PB86-132156

Methods for Assessing Exposure to Chemical Substances. Volume 5 Methods for Assessing Exposure to Chemical Substances in Drinking Water

Versar, Inc., Springfield, VA

Prepared for

Environmental Protection Agency, Washington, DC

Aug 85

U.S. Department of Commerce
National Technical Information Service

NTIS

United States
Environmental Protection
Agency

Office of
Toxic Substances
Washington, D.C. 20460

EPA 560/5-85-005
August 1985

PB86-132156

Toxic Substances

EPA

Methods for Assessing Exposure to Chemical Substances

Volume 5

Methods for Assessing Exposure to Chemical Substances in Drinking Water

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SPRINGFIELD, VA. 22161

50272-101

REPORT DOCUMENTATION PAGE	**1. REPORT NO.** EPA 560/5-85-004	**2.**	**3. Recipient's Accession No.** PB86 132156/AS

4. Title and Subtitle
Methods for Assessing Exposure to Chemical Substances -
Volume 5: Methods for Assessing Exposure to Chemical Substances in Drinking Water

5. Report Date 8/85

6.

7. Author(s) Douglas A. Dixon, Stephen H. Nacht, Gina H. Dixon, Patricia Jennings, Thomas A. Faha

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Versar Inc.
6850 Versar Center
Springfield, Virginia 22151

10. Project/Task/Work Unit No. Task 12

11. Contract(C) or Grant(G) No.
(C) EPA 68-01-6271
(G)

12. Sponsoring Organization Name and Address
United States Environmental Protection Agency
Office of Toxic Substances
Exposure Evaluation Division
Washington, D.C. 20460

13. Type of Report & Period Covered Final Report

14.

15. Supplementary Notes
EPA Project Officer was Michael A. Callahan
EPA Task Manager was Stephen H. Nacht

16. Abstract (Limit: 200 words)

This report, one of a series of reports concerning exposure assessment, describes methods for estimating exposure to chemical substances via drinking water. The report is organized to reflect the framework or flow of required information. Section 2 provides an overview of drinking water systems and the pathways of exposure to chemical substances in drinking water, from the source of the substance through the treatment and distribution systems to the consuming population. Section 3 catalogues and discusses the various data bases and information sources that aid in the identification of contaminated drinking water supplies. Section 4 presents and discusses methods and simulation models that can be used to estimate the concentration of chemical substances in both surface and ground water. Section 5 discusses drinking water treatment systems and processes, the effect the systems and processes have on different types of chemical substances, and how the information can be used to predict the concentration of a chemical substance in finished drinking water. Section 6 briefly discusses the enumeration and characterization of exposed populations; detailed information on this subject is provided in Volume 4 of this series. Finally, Section 7 discusses the procedures for calculating exposure as a result of contact with contaminated drinking water.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

Exposure Assessment/Drinking Water
Toxic Substances/Drinking Water Treatment

c. COSATI Field/Group

18. Availability Statement Distribution unlimited	**19. Security Class (This Report)** Unclassified	**21. No. of Pages** 147
	20. Security Class (This Page) Unclassified	**22. Price**

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

EFA 560/5-85-005
August 1985

METHODS FOR ASSESSING EXPOSURE TO CHEMICAL SUBSTANCES

Volume 5

Methods for Assessing Exposure to Chemical Substances in Drinking Water

by

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OFFICE OF PESTICIDES AND TOXIC SUBSTANCES
WASHINGTON, DC 20460

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FOREWORD

This document is one of a series of volumes, developed for the U.S. Environmental Protection Agency (EPA), Office of Toxic Substances (OTS), that provides methods and information useful for assessing exposure to chemical substances. The methods described in these volumes have been identified by EPA-OTS as having utility in exposure assessments on existing and new chemicals in the OTS program. These methods are not necessarily the only methods used by OTS, because the state-of-the-art in exposure assessment is changing rapidly, as is the availability of methods and tools. There is no single correct approach to performing an exposure assessment, and the methods in these volumes are accordingly discussed only as options to be considered, rather than as rigid procedures.

Perhaps more important than the optional methods presented in these volumes is the general information catalogued. These documents contain a great deal of non-chemical-specific data which can be used for many types of exposure assessments. This information is presented along with the methods in individual volumes and appendices. As a set, these volumes should be thought of as a catalog of information useful in exposure assessment, and not as a "how-to" cookbook on the subject.

The definition, background, and discussion on planning of exposure assessments are discussed in the introductory volume of the series (Volume 1). Each subsequent volume addresses only one general exposure setting. Consult Volume 1 for guidance on the proper use and interrelations of the various volumes and on the planning and integration of an entire assessment.

The titles of the nine basic volumes are as follows:

Volume 1:	Methods for Assessing Exposure to Chemical Substances (EPA 560/5-85-001)
Volume 2:	Methods for Assessing Exposure to Chemical Substances in the Ambient Environment (EPA 560/5-85-002)
Volume 3:	Methods for Assessing Exposure from Disposal of Chemical Substances (EPA 560/5-85-003)
Volume 4:	Methods for Enumerating and Characterizing Populations Exposed to Chemical Substances (EPA 560/5-85-004)
Volume 5:	Methods for Assessing Exposure to Chemical Substances in Drinking Water (EPA 560/5-85-005)

Volume 6: Methods for Assessing Occupational Exposure to Chemical Substances (EPA 560/5-85-006)

Volume 7: Methods for Assessing Consumer Exposure to Chemical Substances (EPA 560/5-85-007)

Volume 8: Methods for Assessing Environmental Pathways of Food Contamination (EPA 560/5-85-008)

Volume 9: Methods for Assessing Exposure to Chemical Substances Resulting from Transportation-Related Spills (EPA 560/5-85-009)

Because exposure assessment is a rapidly developing field, its methods and analytical tools are quite dynamic. EPA-OTS intends to issue periodic supplements for Volumes 2 through 9 to describe significant improvements and updates for the existing information, as well as adding short monographs to the series on specific areas of interest. The first four of these monographs are as follows:

Volume 10: Methods for Estimating Uncertainties in Exposure Assessments (EPA 560/5-85-014)

Volume 11: Methods for Estimating the Migration of Chemical Substances from Solid Matrices (EPA 560/5-85-015)

Volume 12: Methods for Estimating the Concentration of Chemical Substances in Indoor Air (EPA 560/5-85-016)

Volume 13: Methods for Estimating Retention of Liquids on Hands (EPA 560/5-85-017)

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ACKNOWLEDGEMENTS

This report was prepared by Versar Inc. of Springfield, Virginia, for the EPA Office of Toxic Substances, Exposure Evaluation Division, Exposure Assessment Branch (EAB) under EPA Contract No. 68-01-6271 (Task 12). The EPA-EAB Task Manager for this task was Stephen H. Nacht, the EPA Program Manager was Michael Callahan; their support and guidance is gratefully acknowledged. Acknowledgement is also given to Patrick Kennedy of EPA-EED who assisted in the final publication of the report.

A number of Versar personnel have contributed to this task over the three year period of performance, as shown below:

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TABLE OF CONTENTS

Page No.

FOREWORD v

ACKNOWLEDGEMENT vii

TABLE OF CONTENTS ix

LIST OF FIGURES xi

LIST OF TABLES xii

1. INTRODUCTION 1

1.1 Purpose and Scope 1
1.2 Methodological Framework 1

2. DRINKING WATER SYSTEMS AND EXPOSURE PATHWAYS 5

2.1 Sources of Contamination 5
2.2 Drinking Water Supplies 5
2.3 Water Treatment Processes 7
2.4 Distribution Systems 12
2.5 Uses of Finished Water 12
2.6 Water Quality Requirements 14

3. IDENTIFICATION OF CONTAMINATED WATER SUPPLIES 21

3.1 Identification of Surface Water Supplies 21
3.1.1 Hydrologically Linked Data File (HLDF) System ... 21
3.1.2 Federal Reporting Data System (FRDS) 42

3.2 Identification of Ground Water Supplies 43
3.2.1 Identifying Site-Specific Ground Water Supplies . 44
3.2.2 Identifying Non-Site-Specific Ground Water Supplies 46

4. QUANTIFICATION OF RAW WATER CONCENTRATIONS OF CHEMICAL SUBSTANCES 49

4.1 Monitoring Data 49
4.2 Estimation of Concentration in Surface Water 52
4.2.1 Conservative Estimates 52
4.2.2 Chemical Fate Models 65

TABLE OF CONTENTS (Continued)

Page No.

4.3 Estimation of Concentration in Ground Water 72
4.3.1 Release Rate Models 75
4.3.2 Solute Transport Models 78
4.3.3 Practical Model Application 84

5. CONCENTRATION OF CHEMICAL SUBSTANCES IN FINISHED WATER 91

5.1 Public Water Systems 91
5.1.1 Unit Processes in Water Treatment 91
5.1.2 Addition of Contamination During Water Treatment and Distribution 115
5.1.3 Determination of Finished Water Quality 120

5.2 Private Systems 122
5.2.1 Guidelines for Selection of Suitable Private Drinking Water Sources 122
5.2.2 Home Drinking Water Treatment Systems 125

6. EXPOSED POPULATIONS 137

6.1 Identification of Exposed Populations 137
6.2 Enumeration of Exposed Populations 138
6.3 Characterization of Exposed Populations 140

7. CALCULATION OF EXPOSURE 141

7.1 Ingestion Exposure 141
7.2 Dermal Exposure 142
7.3 Inhalation Exposure 142

8. REFERENCES 145

LIST OF FIGURES

Page No.

Figure 1. Framework For Assessing Exposure Via Drinking Water ... 2

Figure 2. Pathways Illustrating Human Exposure to Chemical Substances In Drinking Water 6

Figure 3. Illustration of an Underground Hydrologic System 8

Figure 4. Schematic Representation of an Infiltration Gallery System 9

Figure 5. Schematic Diagrams of Basic Water Treatment Plant Designs 10

Figure 6. IFD Retrieval System Procedure for SIC Code Report 30

Figure 7. Example of a Portion of a SIC Code IFD Retrieval Sorted by NPDES Number 32

Figure 8. Example of WQAB RCHDAT Retrieval for Flow and Facility Information 34

Figure 9. WQAB Sitehelp Example of River Mile Location for REACH 02040201004 36

Figure 10. WQAB Sitehelp Display of Company A Discharge Pipes 37

Figure 11. WQAB Sitehelp Display of Drinking Water Intake for Water Supply Company B 38

Figure 12. Example Pathscan Report 39

Figure 13. Ease of Stripping as a Function of Henry's Law Constants for Selected Organics 101

Figure 14. Chemistry of the Lime-Soda Process 107

LIST OF TABLES

Page No.

Table 1. Summary of Estimated Water Use in the United States, in Billion Gallons Per Day At 5-Year Intervals, 1950-1980 13

Table 2. Water Quality Criteria for Public Water Supplies 15

Table 3. National Interim Primary Drinking Water Standards 17

Table 4. National Profile of Community Water Supply Systems 18

Table 5. Interactive Programs for Accessing Data in the Hydrologically Linked Data Files of EPA Monitoring and Data Support Division 27

Table 6. Percentage of Ground Water Use of Total Water Use For Each State in 1980 48

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) 57

Table 8. Chemical Fate Models for Estimating Pollutant Concentrations in Surface Waters 66

Table 9. EXAMS Input Requirements 73

Table 10. Primary Factors Affecting the Three Components of Leachate Release Rate Models 76

Table 11. Leachate Release Rate Models 77

Table 12. Comparison of Analytical and Numerical Models 79

Table 13. Physical Parameter Characteristics Addressed by Ground Water Models 80

Table 14. Parameter Values Used in SESOIL to Estimate NTA Concentrations in the Unsaturated Zone 85

Table 15. Parameter Values Used in AT123D to Estimate NTA Concentrations in the Saturated Zone 87

LIST OF TABLES (CONTINUED)

Page No.

Table 16. Simulated Average NTA Concentrations in Ground Water at 20 m Depth[1] in an Aquifer of 50 m Average Depth 88

Table 17. Frequency of Use in U.S. of Water Treatment Methods ... 92

Table 18. Removal of Contaminants During Drinking Water Treatment 94

Table 19. Summary of Water Treatment Chemicals CODEX 116

Table 20. Contaminants That May Be Introduced in the Distribution System 119

Table 21. Essential Factors That Should Be Considered in a Sanitary Survey of Ground Water Supplies 123

Table 22. Essential Factors That Should Be Considered in a Sanitary Survey of Surface Water Supplies 124

Table 23. List of Conditions Unfavorable to the Control of Contamination and That May Require Specifying Distances Greater Than 50 Feet for Siting of Wells 126

Table 24. Efficiency of Home Drinking Water Treatment Units Containing Activated Carbon in Removing Trihalomethanes (THMs) and Nonpurgeable Total Organic Carbon (NPTOCs) . 128

Table 25. Range of Percent Specific Halogenated Organic (HO) Reduction for Line Bypass, Faucet-Mount, Stationary, and Pour-Through Units in the Ground Water Study 131

Table 26. Range of Percent Halogenated Organic (HO) Reduction for Line Bypass Faucet-Mount, Stationary, and Pour-Through Units in the Surface Water Study 133

Table 27. Drinking Water Intake Rates and Volumes Consumed by Age and Sex 143

5

1. INTRODUCTION

1.1 Purpose and Scope

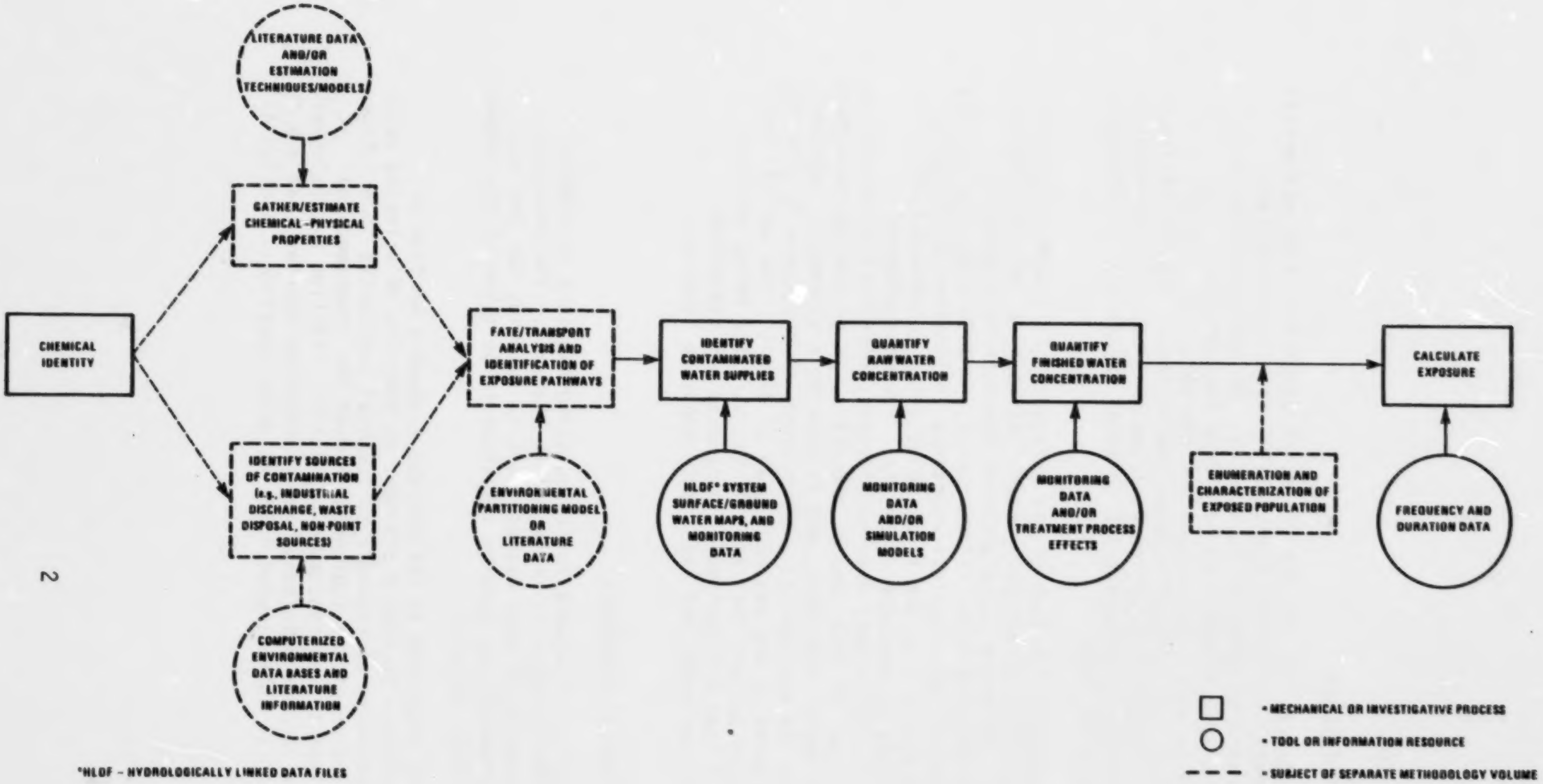
The Toxic Substances Control Act (TSCA) of 1976 (PL94-469) authorizes the U.S. Environmental Protection Agency (EPA) to assess human and environmental exposure to chemical substances. An exposure assessment for a chemical substance attempts to determine the amounts of that chemical substance to which populations are exposed as well as to identify and estimate the size of exposed populations. The EPA Office of Toxic Substances, Exposure Evaluation Division (OTS-EED), is responsible for conducting exposure assessments for chemical substances in support of Sections 4, 5, and 6 of TSCA.

Exposure assessments for each of the categories, including exposure via drinking water, have historically been limited by a lack of complete and reliable data. Accurate calculation of exposure to a chemical substance through drinking water relies heavily on actual monitoring data on the concentration of the chemical substance in finished or processed drinking water, preferably at the final point prior to consumption or other use which leads to exposure - the tap. For most chemical substances, however, these data are insufficient, difficult to obtain, or nonexistent. The goal of this report, therefore, is to catalog pertinent information, data bases, and tools, and to provide a systematic approach or methods whereby the exposure to a given chemical substance in drinking water may be estimated at any desired level of detail. The methods are also applicable when options for reducing exposure are being analyzed. The methods ensure that all pertinent components are evaluated, appropriate values assigned, and reasonable exposure scenarios constructed.

1.2 Methodological Framework

The methodological framework for calculating exposure to chemical substances in drinking water is presented in Figure 1. The framework provides the foundation of this methods report, pointing out the major information requirements and showing the steps to be taken in the proper sequence to calculate exposure.

This volume is organized to reflect the framework or flow of required information. Section 2 provides an overview of drinking water systems and the pathways of exposure to chemical substances in drinking water, from the source of the substance through the treatment and distribution systems to the consuming population. Section 3 catalogues and discusses the various data bases and information sources that aid in the identification of contaminated drinking water supplies. Section 4


CHEMICAL IDENTITY
LITERATURE DATA AND/OR ESTIMATION TECHNIQUES/MODELS
GATHER/ESTIMATE CHEMICAL–PHYSICAL PROPERTIES
IDENTIFY SOURCES OF CONTAMINATION (e.g., INDUSTRIAL DISCHARGE, WASTE DISPOSAL, NON-POINT SOURCES)
COMPUTERIZED ENVIRONMENTAL DATA BASES AND LITERATURE INFORMATION
FATE/TRANSPORT ANALYSIS AND IDENTIFICATION OF EXPOSURE PATHWAYS
ENVIRONMENTAL PARTITIONING MODEL OR LITERATURE DATA
IDENTIFY CONTAMINATED WATER SUPPLIES
HLDF* SYSTEM SURFACE/GROUND WATER MAPS, AND MONITORING DATA
QUANTIFY RAW WATER CONCENTRATION
MONITORING DATA AND/OR SIMULATION MODELS
QUANTIFY FINISHED WATER CONCENTRATION
MONITORING DATA AND/OR TREATMENT PROCESS EFFECTS
ENUMERATION AND CHARACTERIZATION OF EXPOSED POPULATION
CALCULATE EXPOSURE
FREQUENCY AND DURATION DATA
- MECHANICAL OR INVESTIGATIVE PROCESS
- TOOL OR INFORMATION RESOURCE
- SUBJECT OF SEPARATE METHODOLOGY VOLUME

*HLDF – HYDROLOGICALLY LINKED DATA FILES

FIGURE 1. FRAMEWORK FOR ASSESSING EXPOSURE VIA DRINKING WATER

presents and discusses methods and simulation models that can be used to estimate the concentration of chemical substances in both surface and ground water. Section 5 discusses drinking water treatment systems and processes, the effect the systems and processes have on different types of chemical substances, and how the information can be used to predict the concentration of a chemical substance in finished drinking water. Section 6 briefly discusses the enumeration and characterization of exposed populations; detailed information on this subject is provided in Volume 9 of this series. Finally, Section 7 discusses the procedures for calculating exposure as a result of contact with contaminated drinking water.

2. DRINKING WATER SYSTEMS AND EXPOSURE PATHWAYS

A comprehensive assessment of exposure to chemical substances in drinking water requires an understanding of the principles of water supply and distribution. This includes sources of contamination, sources of water for treatment and use, treatment techniques, distribution systems, and the ultimate uses of water.

2.1 Sources of Contamination

Chemical substances of concern may enter water destined for human use by:

- Dissolution from minerals in the environment (e.g., asbestos, arsenic)
- Discharge of industrial or municipal wastewater to surface water
- Leachate from landfills and septic tanks into ground water
- Leakage from above- and underground storage tanks (e.g., gasoline tanks)
- Overflow and seepage from surface impoundments into surface and ground water
- Nonpoint sources of pollution - urban runoff, agricultural and silvicultural runoff, construction runoff, mine drainage, combined (sanitary and stormwater) sewer overflow, spills, washout of atmospheric contaminants, and leachate from chemicals applied to land (e.g., pesticides and other agricultural chemicals)
- Formation or addition of chemical substances during water treatment and distribution (including chemicals leached from tanks and pipes and their linings)

The list is not all-inclusive; it does represent the most common sources of contamination that must be considered in an exposure assessment. Figure 2 summarizes some of the major pathways of exposure to chemical substances in drinking water.

2.2 Drinking Water Supplies

Drinking water supplies are generally classified into two broad categories: surface water and ground water. Surface water supplies include rivers, streams, natural lakes, and impoundments. Sea water and inland saline water are theoretical surface water supplies. However,

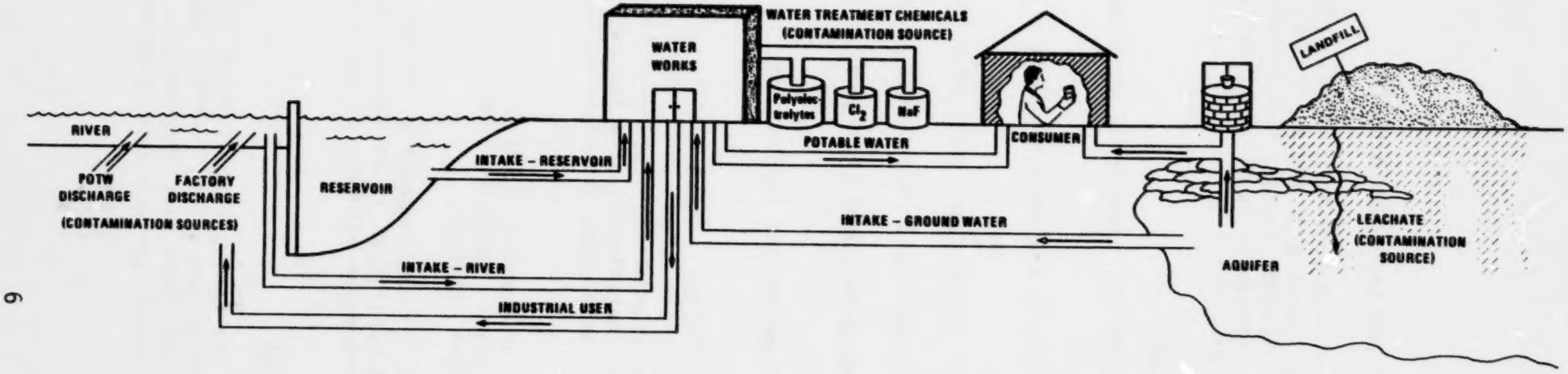

WATER TREATMENT CHEMICALS
(CONTAMINATION SOURCE)
WATER WORKS
Polyelectrolytes
Cl_2
NaF
LANDFILL
RIVER
POTW DISCHARGE
FACTORY DISCHARGE
(CONTAMINATION SOURCES)
RESERVOIR
INTAKE – RESERVOIR
POTABLE WATER
CONSUMER
INTAKE – GROUND WATER
INTAKE – RIVER
INDUSTRIAL USER
AQUIFER
LEACHATE
(CONTAMINATION SOURCE)

FIGURE 2 PATHWAYS ILLUSTRATING HUMAN EXPOSURE TO CHEMICAL SUBSTANCES IN DRINKING WATER

since desalination to render those waters usable is not yet cost-effective on a large scale (Clarke et al. 1977), they are not widely used as drinking water supplies in the United States.

Ground water sources are less easily defined; the term usually refers to wells, springs, and infiltration galleries. Wells are taps into aquifers, which are underground permeable geological units that can transmit economically significant quantities of water under normal hydraulic conditions (Freeze and Cherry 1979). There are two types of aquifers: unconfined aquifers, those that have the water table as their upper boundary; and confined aquifers, those that are bound above and below by relatively impermeable strata. Confined aquifers, under certain geologic conditions, produce artesian wells. Springs are natural surface releases of ground water that may be due to gravity or artesian flow. Figure 3 illustrates an underground hydraulic system including wells, springs, and confined and unconfined aquifers.

Infiltration galleries, also known as filter galleries, are systems constructed in river and lake beds that are designed to collect interstitial water. Usually they are horizontal conduits or pipes with perforations so that ground water can enter by gravity flow (Steel and McGhee 1979). The sand and sediment of the river or lake bed act as a natural filter in these systems, eliminating the need for in-plant filtration. The collected water is then pumped to the treatment plant for further processing and distribution. Infiltration galleries are used in a number of U.S. cities. Figure 4 illustrates a typical infiltration gallery system.

Surface and ground waters to be used as public, private, or industrial supplies are termed raw water prior to treatment; after treatment for improved quality, they are called finished or potable waters. Although there is some distinction between finished and potable water (i.e., finished water is water that has been processed or treated and not necessarily used for drinking purposes; potable water is water that, treated or untreated, is suitable for drinking purposes), the two terms are often used interchangeably. This report will refer to "finished" water throughout.

2.3 Water Treatment Processes

Figure 5 presents simplified flow diagrams for the two most common water treatment schemes. The unit processes comprising these treatment trains are discussed in Section 5 of this report.

Type I (filtration) plants are generally used by municipalities with surface water sources. Chlorine may be added at numerous points to

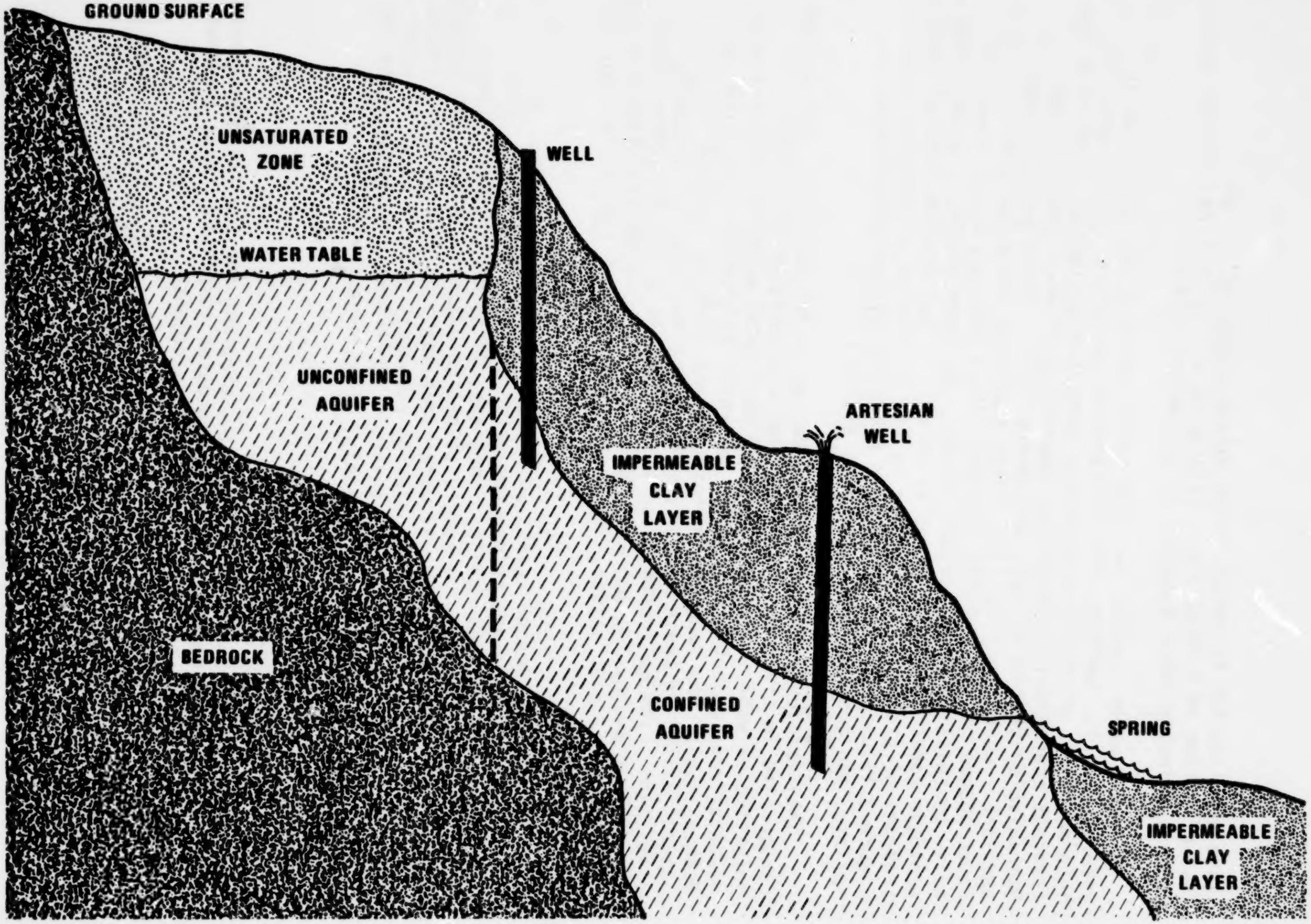

GROUND SURFACE
UNSATURATED ZONE
WATER TABLE
WELL
UNCONFINED AQUIFER
ARTESIAN WELL
IMPERMEABLE CLAY LAYER
BEDROCK
CONFINED AQUIFER
SPRING
IMPERMEABLE CLAY LAYER

FIGURE 3. ILLUSTRATION OF AN UNDERGROUND HYDROLOGIC SYSTEM

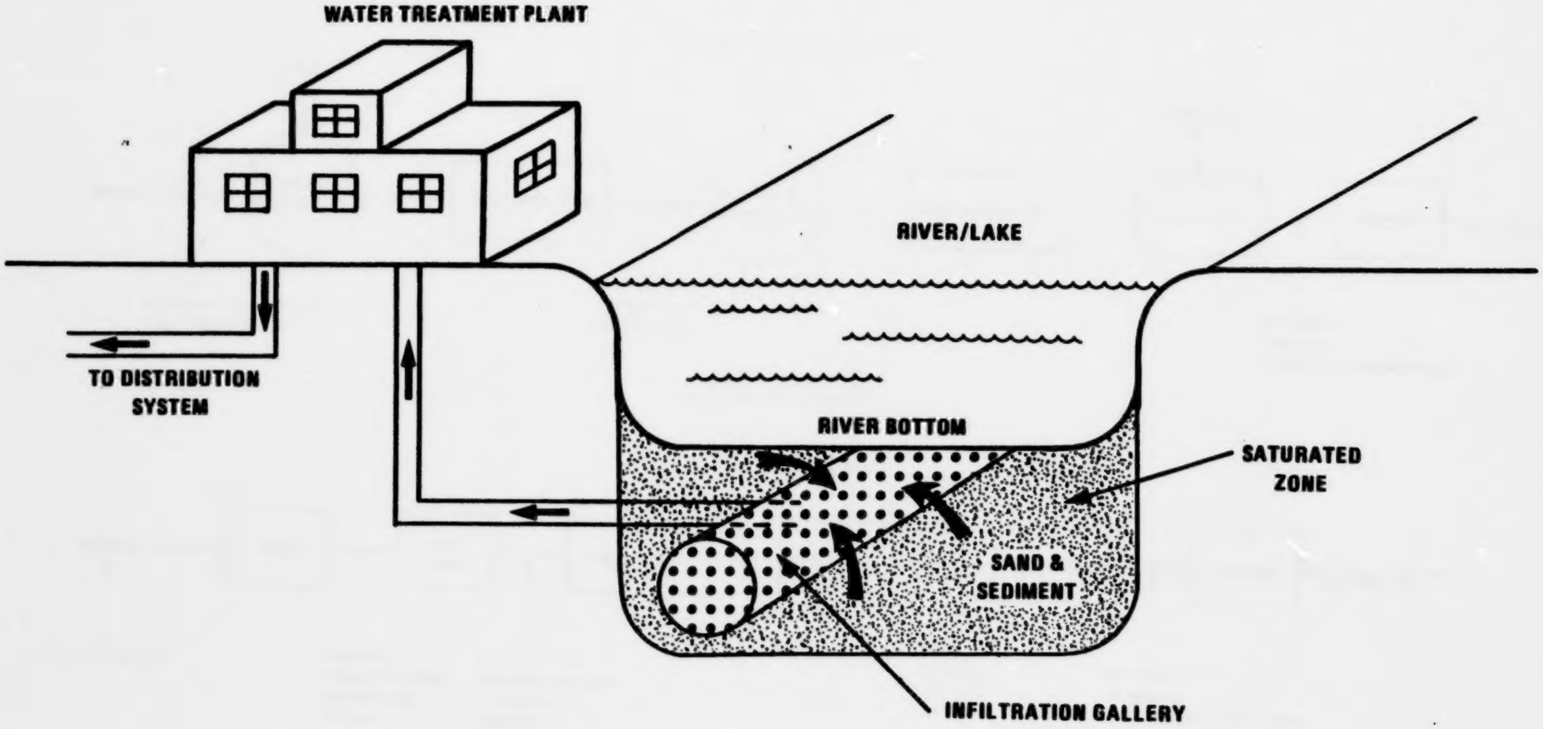
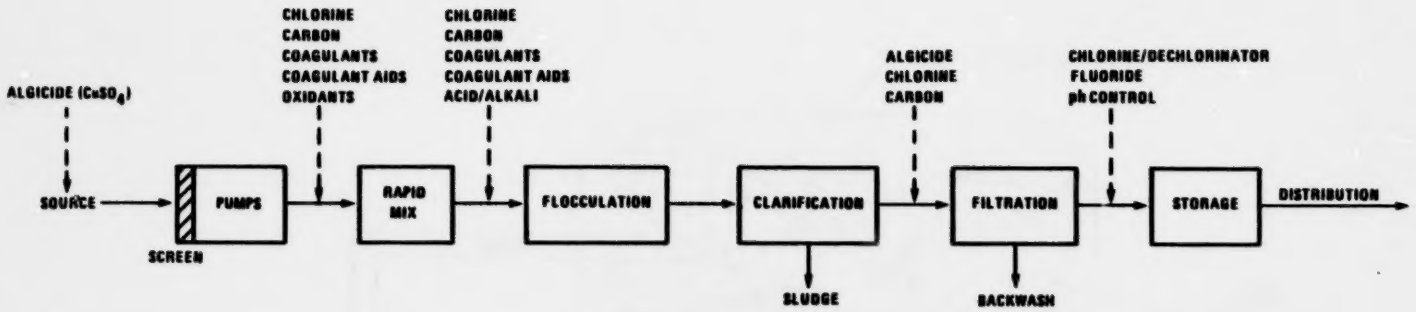
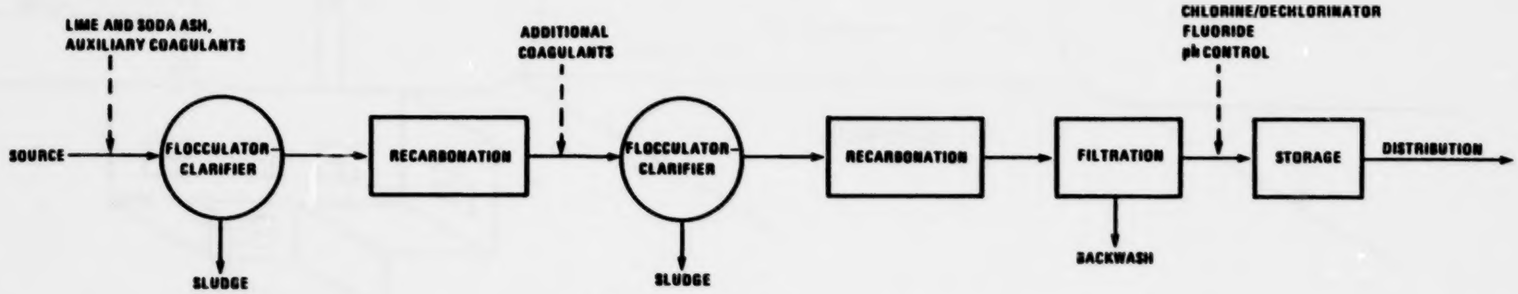

WATER TREATMENT PLANT
TO DISTRIBUTION SYSTEM
RIVER/LAKE
RIVER BOTTOM
SATURATED ZONE
SAND & SEDIMENT
INFILTRATION GALLERY

FIGURE 4. SCHEMATIC REPRESENTATION OF AN INFILTRATION GALLERY SYSTEM


CHLORINE
CARBON
COAGULANTS
COAGULANT AIDS
OXIDANTS
CHLORINE
CARBON
COAGULANTS
COAGULANT AIDS
ACID/ALKALI
ALGICIDE
CHLORINE
CARBON
CHLORINE/DECHLORINATOR
FLUORIDE
ph CONTROL
ALGICIDE ($CuSO_4$)
SOURCE
PUMPS
SCREEN
RAPID MIX
FLOCCULATION
CLARIFICATION
FILTRATION
STORAGE
DISTRIBUTION
SLUDGE
BACKWASH

TYPE I – FILTRATION PLANT


LIME AND SODA ASH,
AUXILIARY COAGULANTS
ADDITIONAL COAGULANTS
CHLORINE/DECHLORINATOR
FLUORIDE
ph CONTROL
SOURCE
FLOCCULATOR-CLARIFIER
RECARBONATION
FLOCCULATOR-CLARIFIER
RECARBONATION
FILTRATION
STORAGE
DISTRIBUTION
SLUDGE
SLUDGE
BACKWASH

TYPE II – SOFTENING PLANT

FIGURE 5. SCHEMATIC DIAGRAMS OF BASIC WATER TREATMENT PLANT DESIGNS (AFTER ASCE 1967; CLARK et al. 1977)

control microbial growth; activated carbon or chemical oxidizing agents (e.g., chlorine compounds, potassium permanganate) are applied to remove organic compounds causing unpleasant tastes and odors. Coagulants (such as alum) are added to remove suspended solids, and oxidants (e.g., ozone and potassium permanganate) may be added to begin decomposition of chemical compounds. The chemicals are blended with the raw water; the mixture is then sent to a flocculation basin.

Flocculation is a process whereby slow mixing of the water and chemicals causes formation of large particles ("floc"); this is both a physical and chemical process. The mixing brings particles together, and electrostatic charges in the coagulants bind them. The floc-laden water is sent to another basin for the solids to settle out (clarification), then the water is filtered through sand or a mixture of media, such as sand, garnet, gravel, or anthracite in layers (ASCE 1967, Clarke et al. 1977).

Softening plants (Type II) are designed to render water usable by removing hardness, strictly defined as divalent cations but largely calcium and magnesium. Hardness is termed carbonate when the calcium and magnesium are present as carbonate or bicarbonate compounds; noncarbonate hardness is magnesium and calcium present as sulfates, nitrates, or chlorides. If not removed, magnesium and calcium compounds often precipitate out of water, causing scale in hot water heaters and in the distribution system and shortening their useful lives. These cations are also nuisances. They combine with soaps used for personal bathing and laundering, rendering them ineffective and causing excessive amounts to be used. It is for these reasons that water is softened (ASCE 1967, Clarke et al. 1977).

Classification of water hardness is not exact; the following is an example of hardness classification (ASCE 1967). Regardless of the chemical form of the hardness, it is expressed as equivalent amounts of calcium carbonate.

- Soft: 0-60 ppm as $CaCO_3$
- Moderately hard: 61-120 ppm as $CaCO_3$
- Hard: 121-180 ppm as $CaCO_3$
- Very hard: >180 ppm as $CaCO_3$

The hardness of a water depends on the geochemistry of the source. Generally, ground waters are harder than surface waters. Waters with hardness of 120ppm $CaCO_3$ are usually softened (ASCE 1967).

The physical treatment process in a softening plant is similar to that of a filtration plant. The chemicals used and their dosages are, however, different. The basic chemical concept of softening is the substitution of sodium ions for magnesium and calcium. The pH of the water is raised (> 11) to precipitate the hardness compounds; this pH adjustment provides a large measure of disinfection as well. The recarbonation step lowers the pH by bubbling CO_2 into the water (Clarke et al. 1977, ASCE 1967).

In the Type II plant schematic, flocculation and clarification are accomplished in one step. The flocculator-clarifier may be used in filtration plants (Type I) as well. Additional unit processes may be used in either type of plant and are discussed in Section 5. Treatment within homes (softeners, carbon filters) is also discussed in that section.

2.4 Distribution Systems

Finished water is generally pumped from the treatment plant throughout the service area. Most modern pressure pipe used in distribution systems is concrete, steel, asbestos-cement, or cast iron; many distribution systems use a combination of these. Some newer systems in temperate climates use plastic distribution pipe. Pressure is maintained throughout the system by intermittent pumping stations and natural head caused by topography (Clarke et al. 1977). Piping within the home need not withstand very high pressures and is often constructed with polyvinyl chloride (PVC). Copper pipe, too expensive for large diameter uses, may also be placed in homes. Contamination may occur in the distribution system by:

- Leaching of metals, chemicals, or fibers from pipe material and joint adhesive
- Infiltration of contaminated water into broken or cracked low pressure water pipe
- Bacterial growth within the distribution system.

2.5 Uses of Finished Water

Table 1 illustrates the trends in water use over the last three decades. It is apparent that withdrawal from public supply grows with the population; per capita use, currently averaging 183 gallons per day, has also grown but at a much lower rate (Solley et al. 1983). Total per capita use includes industrial, commercial, domestic, and public uses. Domestic

Table 1. Summary of Estimated Water Use in the United States, in Billion Gallons Per Day At 5-Year Intervals, 1950-1980

	1950^{1}	1955^{1}	1960^{2}	1965^{2}	1970^{3}	1975^{4}	1980^{4}	Percentage increase or decrease 1975-80
Population, in millions	150.7	164.0	179.3	193.8	205.9	216.4^{5}	229.6	+ 6
Offstream use:								
Total withdrawals	180^{5}	240	270	310	370	420	450	+ 7
Public supply	14	17	21	24	27	29	34	+15
Rural domestic and livestock	3.6	3.6	3.6	4.0	4.5	4.9	5.6	+13
Irrigation	89^{5}	110	110	120	130	140	150	+ 7
Self-supplied industrial:								
Thermoelectric power use:	40	72	100	130	170	200	210	+ 5
Other industrial uses	37	39	38	46	47	45	45	0
Source of withdrawals:								
Ground water:								
Fresh	34	47	50	60	68	82	88	+ 7
Saline	( )^{6}	.6	.4	.5	1	1	.9	-11
Surface water:								
Fresh	140^{5}	180	190	210	250	260	290	+10
Saline	10	18	31	43	53	69	71	+ 3
Reclaimed sewage	( )^{6}	.2	.6^{5}	.7	.5	.5	.5	0
Consumptive use	( )^{6}	( )^{6}	61	77	87^{7}	96^{7}	100^{7}	+ 4
Instream use:								
Hydroelectric power	1,100	1,500	2,000	2,300	2,800	3,300	3,300	0

---

[1] 48 States and District of Columbia
[2] 50 States and District of Columbia
[3] 50 States, District of Columbia, and Puerto Rico
[4] 50 States, District of Columbia, Puerto Rico, and Virgin Islands
Source: Solley et al. (1983).

[5] Corrected from published report.
[6] Data not available.
[7] Fresh water only.

and public use of water, which includes such activities as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets, watering lawns and gardens, firefighting, street washing, and use at municipal parks and in swimming pools, averages 120 gallons per individual per day. Finished water ingested by individuals is a small proportion of total domestic and public use, estimated as approximately 0.5 gallons per day (2 liters) (USEPA 1982a). Human ingestion of drinking water is further discussed in Section 7.

2.6 Water Quality Requirements

Different uses of water require various degrees of quality. Table 2 lists recommended criteria for raw water to be used for public water supplies. Most of these criteria apply to surface waters that have been polluted by industrial, agricultural, and domestic discharges (Clarke et al. 1977); it is implied that treatment will remove most, if not all, the contamination.

Exposure to chemical substances via the ingestion of drinking water was officially recognized as a hazard by the passage in 1974 of the Safe Drinking Water Act (PL 93-523) and its amendment in 1977. The Act set interim drinking water standards for inorganic and organic substances based mostly on health effects that may occur from a lifetime of drinking 2 liters of water per day (CEQ 1979, Clarke et al. 1977). Table 3 lists these standards, known as Maximum Contaminant Levels (MCLs). An MCL of 100 ppb for total trihalomethanes (chloroform and related compounds) was added later; it currently applies only to systems serving more than 10,000 persons (AWWA 1979).

All the drinking water standards apply to public water systems. Public systems serve approximately 84 percent of the U.S. population (see Table 4); the remainder are served by private systems, mostly wells (CEQ 1979).

Ongoing scientific investigation is revealing that exposure to pollutants in drinking water is not limited to exposure via ingestion. Brown et al. (1984) and Scow et al. (1979), for example, report that the body's absorption of water pollutants through the skin - by washing, showering, and bathing - has been seriously underestimated. According to Brown et al. (1984), in fact, for specific organic chemicals such as toluene, ethylbenzene, and styrene, the primary route of exposure for these chemicals may be via dermal absorption. Brown et al. (1984) and Scow et al. (1979) also discuss the potential for volatilization of volatile organic carbons (VOCs) from drinking water and subsequent inhalation while showering and bathing. Exposure to contaminants in drinking water via

Table 2. Water Quality Criteria for Public Water Supplies[a]

Substance	Permissive criterion	Desirable criterion
Coliforms (MPN)	10,000	100
Fecal coliforms (MPN)	2,000	20
Inorganic chemicals (mg/l)		
Ammonia-N	0.5	0.01
Arsenic[b]	0.05	Absent
Barium[b]	1.0	Absent
Boron[b]	1.0	Absent
Cadmium[b]	0.01	Absent
Chloride[b]	250	250
Chromium[b] (hexavalent)	0.05	Absent
Copper[b]	1.0	Virtually absent
Dissolved oxygen	4	Near saturation
Iron	0.3	Virtually absent
Lead[b]	0.05	Absent
Manganese[b]	0.05	Absent
Nitrate[b] – N	10	Virtually absent
Selenium[b]	0.01	Absent
Silver[b]	0.05	Absent
Sulfate[b]	250	50
Total dissolved solids[b]	500	200
Urany ion[b]	5	Absent
Zinc[b]	5	Virtually Absent
Organic chemicals (mg/l)		
Alkyl benzyl sulfonates	—	—
Carbon chloroform extract[b]	0.15	0.04
Cyanide[b]	0.20	Absent
Herbicides 2,4-D + 2,4,5-T + 2,4-TP	0.1	Absent

Table 2. (continued)

Substance	Permissive criterion	Desirable criterion
Oil and grease[b]	Virtually Absent	Absent
Pesticides[b]		
Aldrin	0.017	Absent
Chlordane	0.003	Absent
DDT	0.042	Absent
Dieldrin	0.017	Absent
Endrin	0.001	Absent
Heptachlor	0.018	Absent
Lindane	0.056	Absent
Methoxychlor	0.035	Absent
Toxaphene	0.005	Absent
Phenols[b]	0.001	Absent

[a] Criteria for raw or untreated surface or groundwater.

[b] Substances that are not significantly affected by the following treatment process: coagulation (less than about 50 mg/liter of alum, ferric sulfate, or copperas, with alkali addition as necessary but without coagulant aids or activated carbon), sedimentation (6 hours or less), rapid sand filtration (3 gpm/ft^2 or less), and disinfection with chlorine (without consideration to concentration or form of chlorine residual).

Source: Clarke et al. (1977).

Table 3. National Interim Primary Drinking Water Standards

Constituent	Maximum concentration (in mg/l unless specified)
Inorganic chemicals	
Arsenic	0.05
Barium	1
Cadmium	0.010
Chromium	0.05
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Fluoride	1.4-2.4*
Turbidity	1 TU up to 5 TU
Coliform bacteria	1/100 ml (mean)
Organic chemicals	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5 TP Silvex	0.01
Total trihalomethanes**	0.1
Radionuclides	
Radium 226 and 228 (combined)	5pCi/l
Gross alpha particle activity	15pCi/l
Gross beta particle activity	4 mrem/year

Source: Environment Reporter (1983).

*Depending on annual average maximum daily air temperature; lowest MCL associated with temperatures of 79.3 to 90.5°F (26.3 to 32.5°C).

**The sum of chloroform, bromoform, bromodichloromethane, and chlorodibromomethane.

Table 4. National Profile of Community Water Supply Systems

	Percent of systems	Percent of population
Size of population served		
25-2,499	80	8
2,500-9,999	12	9
10,000 - 1,000,000	8	83
Type of ownership		
Public	56	84
Private	44	16
Primary source of water		
Ground	74	39
Surface	13	49
Purchased[1]	13	12

---

[1] Purchased water refers to drinking water bought from another community system. No data exists on the amount of purchased water that is surface or ground water; however, it is believed that the majority is surface supplied (e.g., the largest wholesalers of drinking water are the State of California, the cities of New York and Chicago, and the Metropolitan District Commission of Boston, all of which obtain drinking water from surface supplies).

Source: CEQ (1979)

dermal absorption and inhalation is a relatively new area of concern with limited technical documentation. No doubt, future investigations will shed considerable new information on this subject.

3. IDENTIFICATION OF CONTAMINATED WATER SUPPLIES

The initial step in assessing exposure to a chemical substance via the ingestion of drinking water is the determination that the chemical substance, based on the sources of the substance and its chemical/physical properties, will be present in water. The identification of the sources of a chemical substance and the environmental releases are part of the materials balance process. The methodology for performing a materials balance is described in JRB (1980). Source analysis is also discussed in Section 2 of Volume 2 of this methods series (i.e., Methods for Assessing Exposure to Chemical Substances in the Ambient Environment). The analysis of fate and transport of a substance to determine the media to which it will partition is discussed in Section 3 of Volume 2.

Once the possibility of exposure to the chemical substance via the ingestion of drinking water is determined, the effort of identifying potentially contaminated drinking water supplies is initiated. The purpose of this section is to provide information that will aid in the identification of raw drinking water supplies that may be contaminated with the chemical due to its release into the environment. Because raw drinking water supplies can essentially be divided into the categories of surface and ground water, and because there are data bases and information resources related to each, the procedures for identifying contaminated surface and ground water supplies are presented separately in the subsequent sections.

3.1 Identification of Surface Water Supplies

This section describes data bases, information resources, and procedures that may be used for identifying surface water supplies which are used as sources of raw drinking water and which are possibly contaminated with the chemical substance of interest. The primary information resources or tools for identifying surface water supplies are the data bases of the Hydrologically Linked Data File (HLDF) system maintained by the EPA Monitoring and Data Support Division, Water Quality Analysis Branch, and the Federal Reporting Data System (FRDS) maintained by the EPA Office of Drinking Water. Each of these systems is described in the following subsections.

3.1.1 Hydrologically Linked Data File (HLDF) System

The HLDF system is a group of data bases that include locational and supporting information relating to industrial wastewater dischargers, receiving water flow rates, water supply intakes, water quality monitoring stations, and fish kills. The data records in the data bases, each of which will be subsequently described, include the name of the water body or reach on which the subject of the data record is located and a unique identifying numeric code called a REACH number. The REACH number, including its derivation and format, will also be subsequently described. The HLDF data bases, therefore, all have a common data record element (i.e., the REACH name and number) to which integrated data base retrievals may be keyed. The data bases are thus "hydrologically linked."

The HLDF system consists of the following minor file, four major files, and one auxiliary file:

I. Minor File

- REACH File

II. Major Files

- Industrial Facilities Discharge (IFD) File
- Water Supply Data Base (WSDB) File
- Stream Gaging Inventory Data (GAGE) File
- Pollution-Caused Fishkill (FISHKILL) File

III. Auxiliary File

- STORET Water Quality Data File

Following is a description of each of these data files except the FISHKILL File, which is not pertinent to this methods report.

REACH File - This file contains a listing of all REACH numbers in the conterminous U.S. By definition, a reach is an arbitrary boundary that defines a certain hydrologic system (e.g., river, stream, lake). In case of a river, the boundary may be defined as the continuous portion of the river where no tributaries intervene (i.e., that portion of the river between the confluence with two tributaries). The REACH number is the mechanism or common data element that hydrologically links the four major and one auxiliary data bases. A REACH number is a combination of the 8-digit U.S. Geological Survey hydrologic unit number (2-digit USGS region number + 2-digit subregion number + 2-digit accounting unit number + 2-digit cataloging unit number.) and an EPA 3-digit segment number. All river basins or portions of river basins in the U.S. have a unique hydrologic unit number. Major water bodies or portions of water bodies within basins, as identified by the hydrologic unit number, have a segment number. Each major stream, river, or lake or segment thereof is uniquely identified, therefore, by the 11-digit REACH number. Detailed information on the USGS hydrologic unit numbering system is available in _State Hydrologic Unit Maps_ - Brochure (USGS undated). The hydrologic unit numbering system is also, along with the EPA segment numbering system, described in _General Information on IFD, Drinking Water Supplies, Stream Gages, Reach, and Fishkill Files and Retrieval Procedures for Hydrologically Linked Data Files_ (USEPA 1981a).

The REACH file consists of approximately 68,000 segments which represent some 700,000 miles of streams or shorelines. An estimated 61,000 of the segments or reaches are stream segments and about 7,000 are shoreline segments. All segments in the REACH file have been linealized (the x, y coordinates (latitude/longitude) have been assigned to all points that define the segment and the sequence of the coordinates that makes up the segment has also been identified), which allows for data retrieval and analysis downstream or upstream of a point or between points. The linealized segment data are used for mapping and location plotting for STORET, IFD, GAGE, FISHKILL, and WSDB data. [Note: See Figure 10, page 37 for a sample REACH file mapping and location plot.]

Industrial Facilities Discharge (IFD) File - IFD is a comprehensive data base of point source dischargers. Currently, there are more than 40,000 direct discharge facilities in the IFD file, of which nearly half are Publicly Owned Treatment Works (POTWs). Included as contributors to POTWs are 11,500 indirect discharge facilities (SCS 1983).

There are 113 data elements within the IFD data file for which data have been collected from various sources; the following are the most important:

(1) Permit Compliance System (PCS) - PCS was used to identify National Pollutant Discharge Elimination System (NPDES) permitted facilities to be included in the IFD file. General information about each facility was extracted from the PCS file to form a building block upon which more specific information could be added.

(2) NPDES Permit Files - The NPDES permits were accessed at the regional EPA offices. Discharge and location information was obtained for both direct and indirect point source dischargers. In addition, various state and local agencies provided additional and more recent information not found in the regional NPDES files.

(3) EPA's 1978 NEEDs Survey File - The NEEDs Survey was used to add information on existing POTWs identified by a NPDES number. Planned POTWs that are required to achieve certain effluent limitations were also included.

The facilities that are included in the IFD file represent an on-going effort that was begun in 1978. An effort of this magnitude requires constant attention in order to reflect current conditions. Every attempt is made by EPA-MDSD to keep the file as up-to-date as possible with the resources that are available.

The industrial facilities in the IFD data file are linked to the REACH data file by a common USGS hydrologic unit number and EPA's segment number. The linkage of IFD with REACH allows the hydrologic pin-pointing of facilities along waterways. This linkage facilitates hydrological analysis of point source discharger information during assessment of potential pollution problems downstream or upstream of a point and between two stream locations.

The IFD data file is organized as a hierarchical information system of three levels: facility level, discharge pipe level, and contributing indirect facility level. This organizational structure allows facilities to be viewed in their entirety or as separate discharge pipes within a facility. The facility level contains identification codes and summarized discharge information (e.g., name, address, NPDES number, city, county, total facility flow, SIC codes, receiving water name). The discharge pipe level includes the components of each individual discharge, such as location, flow, and SIC code activity. The indirect facility level includes data on industrial flow from industries that discharge to another facility, such as a POTW, rather than directly to surface water. [Note: See Figure 7, page 32 for a sample IFD data report.]

Water Supply Data Base (WSDB) - This is the key data file for identifying drinking water systems that use potentially contaminated surface water supplies. The WSDB contains information on the location of surface water utilities; the locations of the utilities' treatment plants, intakes, and sources of raw water; the populations served; and the average and maximum daily production. The locational data for utilities that serve populations greater than 25,000 are very accurate, within ± 5 seconds of latitude-longitude. Locational data for utilities that serve populations fewer than 25,000 are considerably less accurate, within ± 10 minutes of latitude-longitude. All locational data in WSDB have been assigned a REACH number to facilitate the hydrologic linking with other EPA-MDSD data files. [Note: See Figure 12, page 39 for a sample data report linking water supply facilities and industrial facilities that discharge wastewater.] A complete description of WSDB is available in Versar (1981).

Stream Gaging Inventory (GAGE) File - The GAGE data file contains information on approximately 37,000 stream gaging locations throughout the U.S. Information stored includes location of gaging stations, types of data collected, frequency of data collection, media in which data are stored, identification of the collecting agency, and, where available, mean annual flow and 7-day-10-year (7-Q-10) low flow. The latter are mainly estimated flows of the 61,000 stream segments in the REACH file.

Like the previously discussed data files, all locational data in the GAGE file have been assigned the appropriate REACH number. GAGE data, therefore, may be hydrologically linked to the locational data in IFD and WSDB. [Note: See Figures 8 and 12, pages 34 and 39, respectively, for sample HLDF system reports linking IFD, WSDB, and GAGE file data.]

STORET Water Quality Data File - STORET is the major data base for water quality data for EPA. STORET basically includes the locational information for water quality monitoring stations and the inclusive parameter information. Detailed information on STORET, including retrieval options, is described in USEPA (1981b). The STORET User Assistance Group (202-382-7220) will also provide information and assistance in the retrieval of needed data. STORET is considered an auxiliary file in the HLDF system because the locational data have not been assigned REACH numbers. The water quality monitoring stations, however, may be accessed via the mapping capabilities of the HLDF system.

Identification of contaminated surface water supplies relies principally on information contained in IFD and WSDB. As previously mentioned, the HLDF system facilitates an integrated approach to data gathering for other steps in the drinking water exposure assessment process. The entire procedure for locating sources of contamination, affected drinking water supplies, water quality monitoring stations, and gaging stations that contain flow data necessary for estimating the concentration of a chemical substance in raw drinking water supplies will be described later in this report.

There are many retrieval procedures and interactive programs available in the HLDF system. Programs are available for batch processing of data when the number of data entries or the expected amount of data in the retrieval is anticipated to be large. Programs are also available for direct on-line work including the use of a Cathode Ray Tube (CRT) terminal for immediate mapping and display of retrieved information. Retrievals may be performed by the investigator or they may be requested from:

U.S. Environmental Protection Agency
Monitoring and Data Support Division
Water Quality Analysis Branch
Environmental Analysis Section
401 M Street, S.W.
Washington, DC 20460 (202-382-7046)

Retrievals by the investigator will secure the required data much more rapidly, as well as allow the investigator flexibility in the sample retrieval design. However, the following requirements must be considered:

1. The user must have a valid EPA, National Computer Center-IBM (NCC-IBM) computer USERID and account number.
2. The user must be familiar with the text editors of TSO and OBS-WYLBUR (currently supported by NCC-IBM). User guides for TSO and OBS-WYLBUR are available from EPA User's Support Group (202-488-5960).

The major programs for assessing the data in the HDLF system are listed in Table 5. The programs were developed by EPA-MDSD, Water Quality Analysis Branch, and are not part of the STORET user's package. The choice of program or the approach to identifying potentially contaminated drinking water supplies depends on the information initially in hand. Identification may begin with a SIC code(s), NPDES permit number(s), REACH number(s), a political or geographic boundary (e.g., state, county), or a boundary or polygon defined by latitude-longitude coordinates. The possible approaches will be described through examples. The program examples will include:

- Retrieval of industrial dischargers for a specific SIC category, and identification of the REACH number and water body receiving the industrial discharge.

Table 5. Interactive Programs for Accessing Data in the Hydrologically Linked Data Files of EPA Monitoring and Data Support Division

Program name	Text editor	Description
IFDARS	OBS-WYLBUR	The "user friendly" IFD automatic retrieval system allows any user to retrieve NPDES facility, pipe level, or indirect discharge data for assorted criteria. A menu is provided to select standard report formats and several retrieval and selection options. The IFD SIC code retrieval is one of the basic programs that will list, for a specific SIC code, the facility location, the facility flow, and the REACH number of the receiving water body.
WQAB RCHDAT	TSO	Procedure to allow the user interactive access to IFD and GAGE files for stream flow and NPDES pipe discharge data, or discharge flow summary for a user-specified REACH or NPDES number.
HYDRO	TSO	The HYDRO option facilitates the retrieval of data from STORET, IFD, FISHKILL, GAGE, WSDB, and REACH data files in hydrological order. Hydrologic ordering may be in the form of a tree diagram, or a digital plotted location map. The results of a STORET analysis of water quality data at individual stations appear in hydrological sequence together with data from the other files.
PATHSCAN	TSO	Interactive version of HYDRO. Procedure to allow the user interactive use of IFD, water supply, gage and stream reach files to retrieve NPDES and drinking water facilities upstream or downstream from a specified location.

Table 5. (continued)

Program name	Text editor	Description
SITEHELP*	TSO	Interactive procedure to facilitate assigning and retrieving of river mileage locations to IFD pipes, stream flow gaging stations, drinking water supplies, and STORET water quality monitoring stations. This procedure graphically displays data locations and stream segment using a CRT terminal. This procedure can be used to browse IFD, GAGE, WSDB, and STORET files, for example, to assist environmental analysis and modeling.
IHSBRWSE	TSO	Procedure to allow the user interactive access to data in the HLDF system, (i.e., IFD, GAGE, WSDB, REACH).

Source: USEPA, Monitoring and Data Support Division, Water Quality Analysis Branch.

*Program requires the use of a Tektronix CRT terminal to assign river mile locations. However, any standard terminal can be used to browse the HLDF system.

- Retrieval of flow data for a receiving water body.

- Assignment and retrieval of river mile locations for industrial dischargers, drinking water intakes, water quality monitoring stations, and gage locations.

- Retrieval of industrial dischargers, drinking water intakes, water quality monitoring stations, and flow gages in hydrological (upstream) order.

- Identification of a REACH number(s) and subsequent identification of a raw surface drinking water supply(s) contaminated by a waste disposal site, spill, or a nonpoint source of pollution.

Following are example programs:

EXAMPLE #1 - IFD Retrieval Using SIC Code: The materials balance and fate and transport analysis for a chemical substance determines that the chemical is discharged to and is persistent in surface water. Environmental release occurs from manufacture of the substance. The manufacturing facilities are included in a known SIC category. Human exposure may occur via drinking water if the substance contaminates raw surface water supplies.

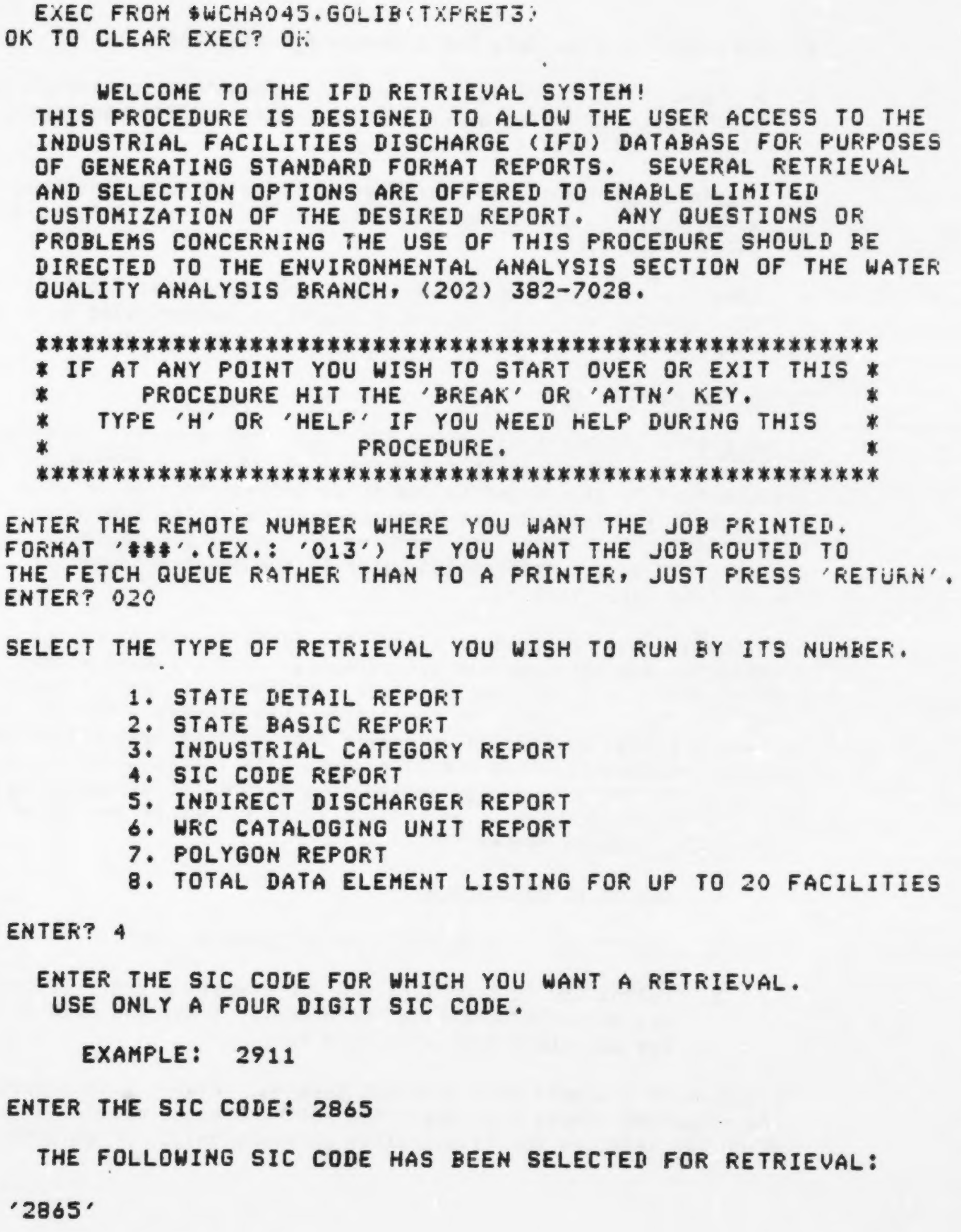
The IFD File will be used to access the facility and discharge information for the specific SIC category. The EPA-MDSD Water Quality Analysis Branch has provided automatic retrieval procedures which are "user friendly" to facilitate this process. The retrieval procedure (known as TXPI004 Automatic Retrieval System) allows the user to retrieve facility and pipe level data for assorted criteria. In addition, the data can be sorted in a variety of different ways. The retrieval procedure is as follows (user responses are shown in lower case, between quotes.):

1. Log on to OBS-WYLBUR.

2. Type "exec from $wcha045 golib(txpret3) clr".

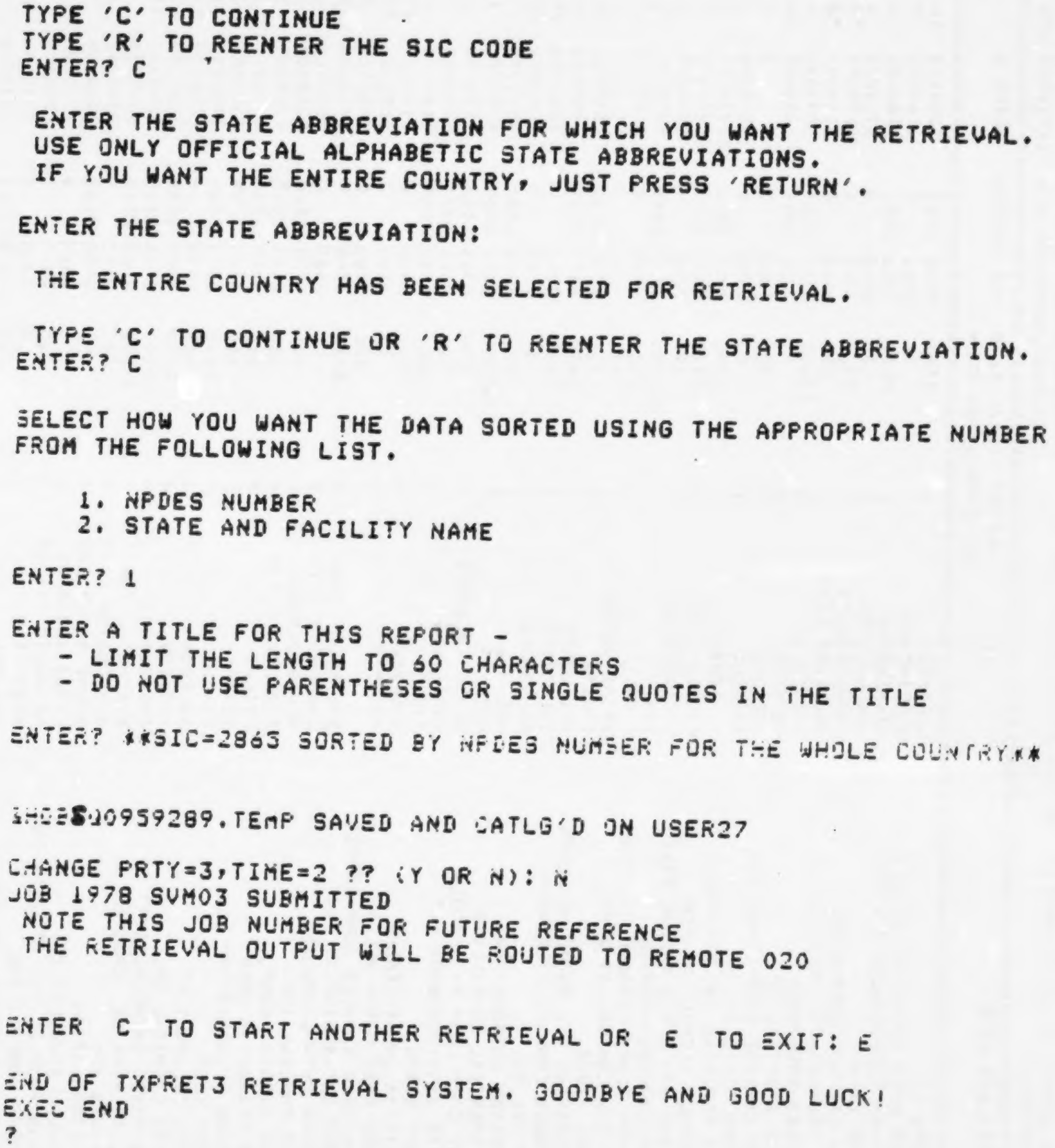
3. Follow the instructions and the prompts given. If problems are encountered during the process, press the ATTN or BREAK key and start over with step two.

Figure 6 is a sample of a terminal session. Figure 7 is a portion of the resulting sample retrieval (SIC 2865 - Organic chemicals Industry, which was selected for illustrative purposes only). From this



```
  EXEC FROM $WCHA045.GOLIB(TXPRET3)
OK TO CLEAR EXEC? OK

      WELCOME TO THE IFD RETRIEVAL SYSTEM!
  THIS PROCEDURE IS DESIGNED TO ALLOW THE USER ACCESS TO THE
  INDUSTRIAL FACILITIES DISCHARGE (IFD) DATABASE FOR PURPOSES
  OF GENERATING STANDARD FORMAT REPORTS.  SEVERAL RETRIEVAL
  AND SELECTION OPTIONS ARE OFFERED TO ENABLE LIMITED
  CUSTOMIZATION OF THE DESIRED REPORT.  ANY QUESTIONS OR
  PROBLEMS CONCERNING THE USE OF THIS PROCEDURE SHOULD BE
  DIRECTED TO THE ENVIRONMENTAL ANALYSIS SECTION OF THE WATER
  QUALITY ANALYSIS BRANCH, (202) 382-7028.

  ****************************************************
  * IF AT ANY POINT YOU WISH TO START OVER OR EXIT THIS *
  *      PROCEDURE HIT THE 'BREAK' OR 'ATTN' KEY.      *
  *   TYPE 'H' OR 'HELP' IF YOU NEED HELP DURING THIS   *
  *                   PROCEDURE.                        *
  ****************************************************

ENTER THE REMOTE NUMBER WHERE YOU WANT THE JOB PRINTED.
FORMAT '###'.(EX.: '013') IF YOU WANT THE JOB ROUTED TO
THE FETCH QUEUE RATHER THAN TO A PRINTER, JUST PRESS 'RETURN'.
ENTER? 020

SELECT THE TYPE OF RETRIEVAL YOU WISH TO RUN BY ITS NUMBER.

        1. STATE DETAIL REPORT
        2. STATE BASIC REPORT
        3. INDUSTRIAL CATEGORY REPORT
        4. SIC CODE REPORT
        5. INDIRECT DISCHARGER REPORT
        6. WRC CATALOGING UNIT REPORT
        7. POLYGON REPORT
        8. TOTAL DATA ELEMENT LISTING FOR UP TO 20 FACILITIES

ENTER? 4

  ENTER THE SIC CODE FOR WHICH YOU WANT A RETRIEVAL.
   USE ONLY A FOUR DIGIT SIC CODE.

     EXAMPLE:  2911

ENTER THE SIC CODE: 2865

  THE FOLLOWING SIC CODE HAS BEEN SELECTED FOR RETRIEVAL:

'2865'
```

Figure 6. IFD Retrieval System Procedure for SIC Code Report



```
TYPE 'C' TO CONTINUE
TYPE 'R' TO REENTER THE SIC CODE
ENTER? C

 ENTER THE STATE ABBREVIATION FOR WHICH YOU WANT THE RETRIEVAL.
 USE ONLY OFFICIAL ALPHABETIC STATE ABBREVIATIONS.
 IF YOU WANT THE ENTIRE COUNTRY, JUST PRESS 'RETURN'.

ENTER THE STATE ABBREVIATION:

 THE ENTIRE COUNTRY HAS BEEN SELECTED FOR RETRIEVAL.

 TYPE 'C' TO CONTINUE OR 'R' TO REENTER THE STATE ABBREVIATION.
ENTER? C

SELECT HOW YOU WANT THE DATA SORTED USING THE APPROPRIATE NUMBER
FROM THE FOLLOWING LIST.

     1. NPDES NUMBER
     2. STATE AND FACILITY NAME

ENTER? 1

ENTER A TITLE FOR THIS REPORT -
   - LIMIT THE LENGTH TO 60 CHARACTERS
   - DO NOT USE PARENTHESES OR SINGLE QUOTES IN THE TITLE

ENTER? **SIC=2863 SORTED BY NPDES NUMBER FOR THE WHOLE COUNTRY**


SHC2$00959289.TEMP SAVED AND CATLG'D ON USER27

CHANGE PRTY=3,TIME=2 ?? (Y OR N): N
JOB 1978 SVM03 SUBMITTED
 NOTE THIS JOB NUMBER FOR FUTURE REFERENCE
 THE RETRIEVAL OUTPUT WILL BE ROUTED TO REMOTE 020


ENTER  C  TO START ANOTHER RETRIEVAL OR  E  TO EXIT: E

END OF TXPRET3 RETRIEVAL SYSTEM. GOODBYE AND GOOD LUCK!
EXEC END
?
```

Figure 6. IFD Retrieval System Procedure for SIC Code Report
(continued)

```
                                     TXPIFD    REPORT            10/15/84                           PAGE    1
  *  **SIC=2865 SORTED BY NPDES NUMBER FOR THE WHOLE COUNTRY**  *    EPA-ENVIRONMENTAL ANALYSIS SECTION
  ***SIC CODE REPORT***                                             WQAB,MDSD,OWPS-EPA <<< "TXPI004" IFD DATABASE >>>
====================================================================================================================
 NPDES#     FACILITY NAME                          CITY      NUMBER  TOTAL FLOW  SIC CODE<S>  REACH #     INDUSTRIAL
                                                            OF PIPES -1000 GPD-                            CATEGORY<S>
====================================================================================================================
AL0000680  KOPPERS CO                        WOODWARD            6      8760   3312 3313   3160112  16  07
AL0002097  ALLIED CHEM SOLVAY DV FAIRFL      BIRMINGHAM          1        72   2865    0   3160111   4  12 31
AL0003247  NO B'HAM COMPLEX-JIM WALTER       BIRMINGHAM          1      6500   3312 3321   3160111   6  07
AL0026174  ALPINE LABS                       BAY MINETTE         1       590   2865    0   3160204   6  12
AL0027596  COOSA CHEM-CHILDERSBURG           CHILDERSBURG        1      37.5   2865    0   3150107  55  12
DE0020001  STD. CHLORINE OF DELAWARE         DELAWARE CITY       1       250   2865    0   2040204  52  12
GA0003735  HERCULES-BRUNSWICK                BRUNSWICK           2     23600   2861 2865   3070203   1  12 22
IL0003191  PIERCE CHEMICAL CO                ROCKFORD            2         9   2834 2865   7090005  16  12 20
IN0037800  UNION CARBIDE CORP LINDE DIV      WHITING             1       290   2865    0         0   0
IN0044113  SEYMOUR RECYCLING                 SEYMOUR             1        80   2865    0   5120206   2  12
KS0000761  GETTY REFINING AND MARKETING C    EL DORADO           1      1340   2911 2865  11030017   2  23
KS0001651  REICHHOLD CHEMICALS, KCK          KANSAS CITY         2      1510   2821 2865  10240011   1  31
KY0042421  ASHLAND SYN FUELS H-COAL PILOT    CATLETTSBURG        1       196   2865    0   5070204   1  12
LA0000191  UNION CARBIDE-HAHNVILLE           TAFT                1    482000   2869 2865   8090100  22
LA0003751  COS-MAR PLANT (COSDEN OIL)--2A    CARVILLE            1      2030   2865    0   8070100   7  31
LA0029963  GULF OIL COMPANY-ST JAMES         SAINT JAMES         1      1580   2865    0   8070100   1  31
MA0003344  SAMUAL CABOT                      CHELSEA             2       7.4   2865 2851   1090001  15  12
MD0000540  CONTINENTAL OIL BALTO PETRO PL    BALTIMORE           1      1070   2819 2865   2060003  28  33
MD0001066  JS YOUNG COMPANY-BALTIMORE        BALTIMORE           1      16.4   2865    0   2060003  25  12
MD0024708  GULF OIL CO.                      BALTIMORE           1        30   2865    0   2060003  22  12
MI0000761  CHEMETRON CORPORATION             HOLLAND             1       900   2865 2851   4050002  13
MI0000868  DOW CHEMICAL CO-MIDLAND           MIDLAND            10    167000   2812 2865   4080201   1  22 06
MS0001791  FIRST CHEM CORP PASCAGOULA        BAYOU CASSOTTE      1       450   2865 2812   3170009   1  12
MS0027995  VERTAC INC-VICKSBURG PLT          VICKSBURG           1      1500   2812 2873   8060100   7  22 33
MS0029190  CROSBY CHEMS                      PICAYUNE            1      3800   2865 2869   3180004   4  12
MS0034878  PLASTIFAX INC-GULFPORT            GULFPORT            1       7.2   2865    0   3170009  35  12
NC0004138  SO TEX CHEM MOUNT HOLLY           MOUNT HOLLY         1        93   2865    0   3050101  12  31
NC0005274  CROMPTON & KNOWLES CORP-LOWELL                        1       300   2865    0   3050102   1  31
NC0027065  PFIZER INC-SOUTHPORT PLT          SOUTHPORT TOWN      1      2030   2865    0   3030005   5  31
NC0039128  FORSHAW CHEM-CHARLOTTE            CHARLOTTE CITY      1         1   2865    0   3050103  31  12
NJ0000060  RHONE POULENC INC                 NEW BRUNSWICK       2       206   4931 2865   2030105   2  12 15 20
NJ0000256  UNION CARBIDE CORP.               PISCATAWAY TWP      2       320   2821 2865   2030105   2  12
NJ0001112  BASF WYANDOTTE CORP               KEARNY              2       512   2819 2865   2030103  10  31 33
NJ0001694  KOPPERS CO.-SEABOARD PL.          KEARNY              1       560   2865 2869   2030103   1  37
NJ0002453  INMONT CORP                       HAWTHORNE           2      1610   2851 2865   2030103  12  12
NJ0003174  HARMON COLORS CORP                HALEDON             2       604   2865    0   2030103  12
NJ0003182  STEPAN CHEMICAL CO.               MAYWOOD             2      2300   2869 2865   2030103   1  31
NJ0004120  TOMS RIVER CHEMICAL CORP          DOVER/TWP/          4     18000   2821 2865   2040301  15  12
NJ0004219  E.I. DU PONT DE NEMOURS           GREENWICH TWP       7     35200   2865 2819   2040202  15  31
NJ0005142  HERCULES INC                      BURLINGTON /TWP     2       747   2865    0   2040201   4  31
NJ0021806  GAF CORPORATION                   BOUND BROOK BOR     2       193   2952 2865   2030105   5
NJ0028991  RANDOLPH PRODUCTS CO              CARLSTADT BORO      1         1   2865    0   2030103   1
NJ0032662  WILSON PROD CO-DIV OF DART IND    NESHANIC STATIO     3       7.5   2865    0   2030105  17  12
NJ0032751  KOPPERS COMPANY INC               WESTFIELD           1        .5   2865    0   2030104  16
NJ0033430  FAIRMOUNT CHEMICAL CO INC         NEWARK              2       462   2899 2865   2030103  10  31
```

Figure 7. Example of a Portion of a SIC Code IFD Retrieval Sorted by NPDES Number .

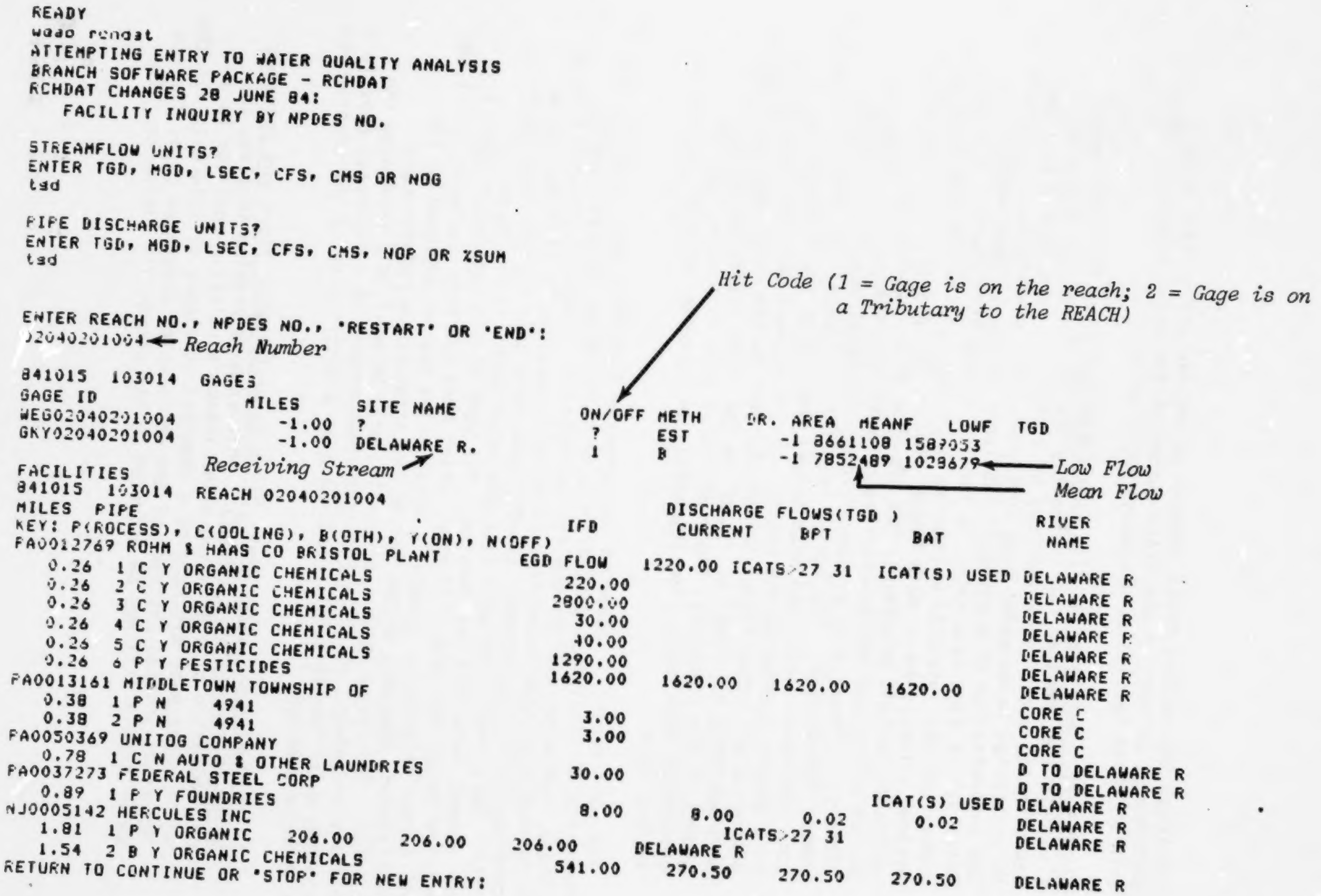
*Retrievals can also be sorted by State and facility name.

retrieval the various NPDES numbers of the facilities have been determined, as well as the REACH number of the water bodies to which each of these facilities discharge waste water.

EXAMPLE #2 - Retrieval of Flow Data (WQAB RCHDAT): Receiving water flow data are required for estimating the in-stream concentration (or raw drinking water concentration) of a chemical substance discharged in industrial waste water (see Section 4.2 for procedures to estimate the concentration of a chemical substance in raw surface water). Retrieval of flow data requires the use of the REACH number or NPDES number and the interactive program under TSO, of the EPA-IBM computer system, referred to as WQAB RCHDAT (Note: for a user to become STORET validated in this procedure, the EPA-MDSD Water Quality Analysis Branch will place the interactive program into the user's command library). Figure 8 is an example of a retrieval session for REACH number 02040201004. The output from this retrieval includes the reach name (Delaware River) and mean annual and 7-Q-10 low stream flows for each gaging station on the reach. This procedure can also be used to determine all other industrial dischargers on the reach (by responding with anything but "nop" or "%sum" to the "PIPE DISCHARGE UNITS?" prompt by the computer), their discharge pipe flow rate, and the percentage that their flow represents in relation to other industries on the reach.

EPA was recently engaged in two programs entailing the assigning of river miles to industrial dischargers, drinking water intakes, gaging stations, and water quality monitoring stations. EPA-MDSD concentrated on 400 reaches that they determined to be most impacted by Best Available Technology (BAT) regulations; EPA-OTS made more than 10,000 assignments to reaches where industries with frequent occurrences in the Canonical Environments Data Base are located. The WQAB RCHDAT retrieval identifies the river miles assigned. If river miles have not been assigned, a "-1.00" will appear in place of a value. River miles may be assigned by the investigator, however, by the use of the interactive program WQAB SITEHELP. This program will be particularly helpful in determining the relative hydrologic position (upstream/downstream) of a discharge pipe to a drinking water intake point. Following is a description of the program and an example problem:

Example #3 - Assigning River Miles to Waste Water Pipes and Drinking Water Intakes (WQAB SITEHELP): This example problem involves the determination of a drinking water intake's relative position to a waste water pipe discharging a chemical substance of interest. If the intake is located upstream of the waste water discharge pipe, the raw water supply will not be affected by the chemical's discharge. The



```
READY
wqao rchdat
ATTEMPTING ENTRY TO WATER QUALITY ANALYSIS
BRANCH SOFTWARE PACKAGE - RCHDAT
RCHDAT CHANGES 28 JUNE 84:
   FACILITY INQUIRY BY NPDES NO.

STREAMFLOW UNITS?
ENTER TGD, MGD, LSEC, CFS, CMS OR NOG
tgd

PIPE DISCHARGE UNITS?
ENTER TGD, MGD, LSEC, CFS, CMS, NOP OR %SUM
tgd

ENTER REACH NO., NPDES NO., 'RESTART' OR 'END':
02040201004

841015  103014  GAGES
GAGE ID                    MILES     SITE NAME                ON/OFF METH    DR. AREA  MEANF    LOWF   TGD
WEG02040201004              -1.00   ?                           ?     EST          -1 8661108 1587053
GKY02040201004              -1.00   DELAWARE R.                 1     B            -1 7852489 1029679

FACILITIES
841015  103014  REACH 02040201004
MILES  PIPE                                                         DISCHARGE FLOWS(TGD )
KEY: P(ROCESS), C(OOLING), B(OTH), Y(ON), N(OFF)         IFD        CURRENT    BPT        BAT          RIVER
FA0012769 ROHM & HAAS CO BRISTOL PLANT                                                                   NAME
   0.26  1 C Y ORGANIC CHEMICALS                      EGD FLOW   1220.00 ICATS>27 31  ICAT(S) USED DELAWARE R
   0.26  2 C Y ORGANIC CHEMICALS                         220.00                                    DELAWARE R
   0.26  3 C Y ORGANIC CHEMICALS                        2800.00                                    DELAWARE R
   0.26  4 C Y ORGANIC CHEMICALS                          30.00                                    DELAWARE R
   0.26  5 C Y ORGANIC CHEMICALS                          40.00                                    DELAWARE R
   0.26  6 P Y PESTICIDES                               1290.00                                    DELAWARE R
FA0013161 MIDDLETOWN TOWNSHIP OF                        1620.00    1620.00    1620.00    1620.00   DELAWARE R
   0.38  1 P N    4941                                                                             DELAWARE R
   0.38  2 P N    4941                                     3.00                                    CORE C
FA0050369 UNITOG COMPANY                                   3.00                                    CORE C
   0.78  1 C N AUTO & OTHER LAUNDRIES                                                              CORE C
FA0037273 FEDERAL STEEL CORP                              30.00                                    D TO DELAWARE R
   0.89  1 P Y FOUNDRIES                                                                           D TO DELAWARE R
NJ0005142 HERCULES INC                                                                ICAT(S) USED DELAWARE R
   1.81  1 P Y ORGANIC    206.00     206.00               8.00       8.00       0.02       0.02    DELAWARE R
   1.54  2 B Y ORGANIC CHEMICALS                     206.00      DELAWARE R   ICATS>27 31          DELAWARE R
RETURN TO CONTINUE OR 'STOP' FOR NEW ENTRY:               541.00     270.50     270.50     270.50   DELAWARE R
```

Hit Code (1 = Gage is on the reach; 2 = Gage is on a Tributary to the REACH)

Reach Number

Receiving Stream

Low Flow

Mean Flow

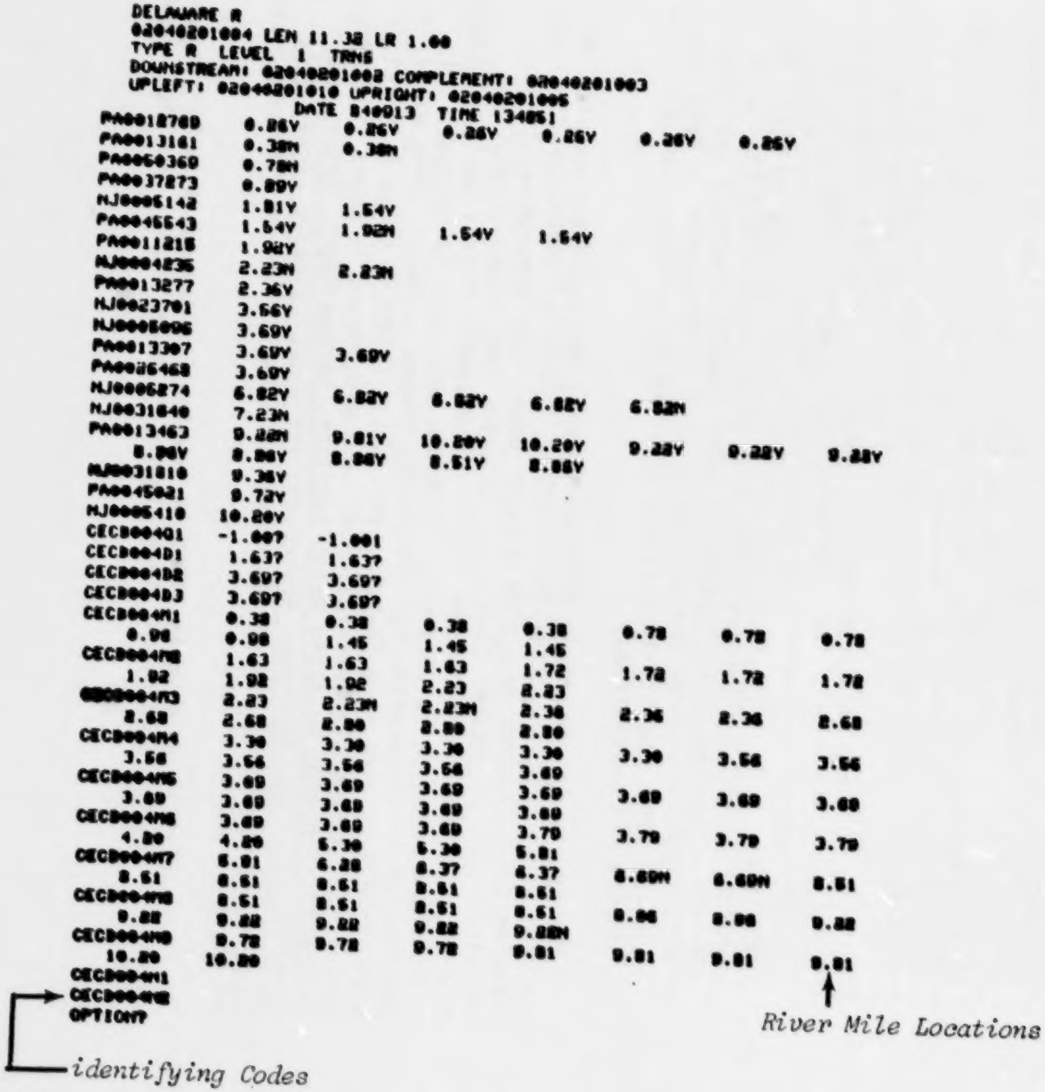
Figure 8. Example of WQAB RCHDAT Retrieval for Flow and Facility Information

TSO interactive program to accomplish this goal and to assign "river mile locations" is referred to as WQAB SITEHELP. The program is accessed via the same procedure as WQAB RCHDAT. Because of its graphic nature, however, the program requires the use of a Tektronix CRT terminal to assign river mile locations. Complete details on the procedures used to retrieve and assign river mile locations, through the use of the SITEHELP procedure, may be obtained from EPA-MDSD.

The IFD retrieval (see Example #1) identified Company A in New Jersey (NPDES number NJ0005142) as discharging to REACH 02040201004. Typing in this REACH number results in a graphic display of the reach and the relative location of this facility to one drinking water intake, as illustrated in Figure 9. Located on this example Reach are: 19 industrial facilities (as designated by the 19 unique NPDES numbers); three drinking water intakes (as depicted by the 9-digit identification code with D1, D2, and D3; and nine sets of monitoring stations (as identified by the 9-digit identification codes ending with M1-M9. (Note: a set of monitoring stations can contain as many as 12 separate stations.) The river flow is always in the direction of "x", as shown in the example. Company A's second discharge pipe is located at river mile 1.81 and the drinking water intake is located downstream at river mile 1.63 (see, also, Figure 10). A subsequent retrieval, Figure 11, lists the drinking water utility as Water Supply Company B, which withdraws water from REACH 02040201004 (Delaware River). The raw water intakes of Water Supply Company B are just 0.18 miles downstream from the wastewater pipe of Company A. Therefore, the raw water quality is possibly affected by chemical substances in Company A's wastestream.

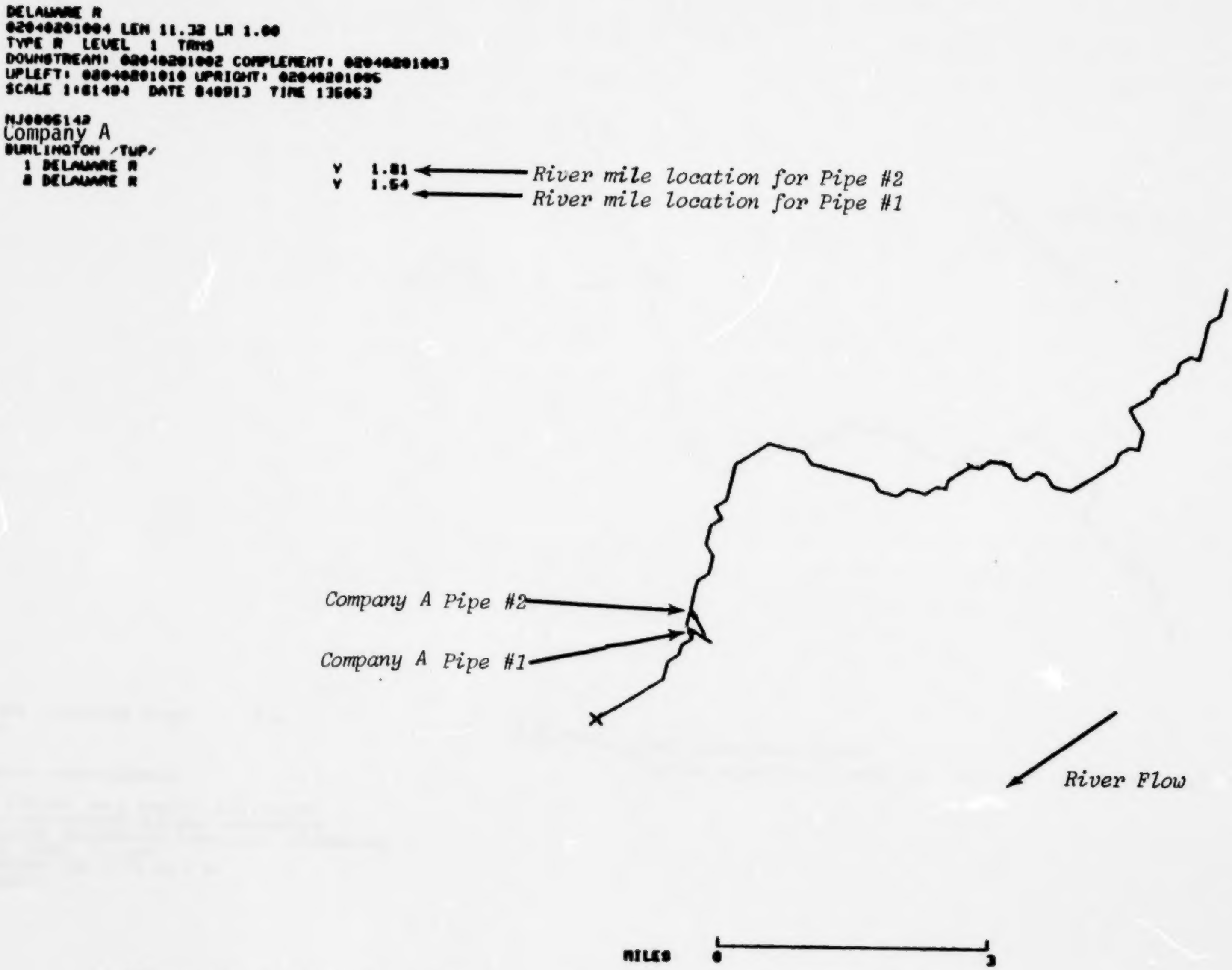
The previously described interactive program (SITEHELP) enables the user to identify the relative locations of industrial discharge pipes and drinking water intakes on a single water body. The program will not identify pipes or intakes that occur in water body segments that are downstream of the segment under study. To accomplish this goal, a "HYDRO" or PATHSCAN" program is required. Although both provide the user with information on consecutive hydrologically linked segments, they differ in that "HYDRO" is used in a "batch mode", while PATHSCAN is an interactive procedure. A complete description of both procedures is found in General Information on IFD: Drinking Water Supplies, Stream Gages, Reach, and Fishkill Files and Retrieval Procedures for Hydrologically Linked Data Files (USEPA 1981a). Discussion herein will be limited to Pathscan because of its interactive nature.

Figure 12 is an example PATHSCAN session for Company A, NPDES Number NJ0005142, REACH 02040201004, investigated in example #1. The NPDES number



```
DELAWARE R
02040201004 LEN 11.38 LR 1.00
TYPE R  LEVEL  1  TRNS
DOWNSTREAM: 02040201002 COMPLEMENT: 02040201003
UPLEFT: 02040201010 UPRIGHT: 02040201005
                 DATE 840913  TIME 134851
PA0012780    0.26V    0.26V    0.26V    0.26V    0.26V    0.26V
PA0013161    0.38M    0.38M
PA0060360    0.78M
PA0037273    0.89V
NJ0005142    1.01V    1.54V
PA0046543    1.54V    1.92M    1.54V    1.54V
PA0011215    1.92V
NJ0004235    2.23M    2.23M
PA0013277    2.36V
NJ0023701    3.56V
NJ0005606    3.69V
PA0013307    3.69V    3.69V
PA0026468    3.69V
NJ0005274    6.82V    6.82V    6.82V    6.82V    6.82M
NJ0031640    7.23M
PA0013463    9.22M    9.01V   10.20V   10.20V    9.22V    9.22V    9.22V
    8.86V    8.86V    8.86V    8.51V    8.86V
NJ0031810    9.36V
PA0045021    9.72V
NJ0005410   10.20V
CECD004Q1   -1.00?   -1.001
CECD004D1    1.63?    1.63?
CECD004D2    3.69?    3.69?
CECD004D3    3.69?    3.69?
CECD004M1    0.38     0.38     0.38     0.38
    0.98     0.98     1.45     1.45     1.45     0.78     0.78     0.78
CECD004M2    1.63     1.63     1.63     1.72
    1.92     1.92     1.92     2.23     2.23     1.72     1.72     1.72
CECD004M3    2.23     2.23M    2.23M    2.36
    2.60     2.60     2.80     2.80     2.80     2.36     2.36     2.60
CECD004M4    3.30     3.30     3.30     3.30
    3.56     3.56     3.56     3.56     3.69     3.30     3.56     3.56
CECD004M5    3.69     3.69     3.69     3.69
    3.69     3.69     3.69     3.69     3.69     3.69     3.69     3.69
CECD004M6    3.69     3.69     3.69     3.79
    4.20     4.20     5.30     5.30     5.01     3.79     3.79     3.79
CECD004M7    5.01     6.20     6.37     6.37
    8.51     8.51     8.51     8.51     8.51     6.60M    6.60M    8.51
CECD004M8    8.51     8.51     8.51     8.51
    9.22     9.22     9.22     9.22     9.22M    9.06     9.06     9.22
CECD004M9    9.78     9.78     9.78     9.81
   10.20    10.20                                 9.81     9.81     9.81
CECD004N1
CECD004N2
OPTION?
```

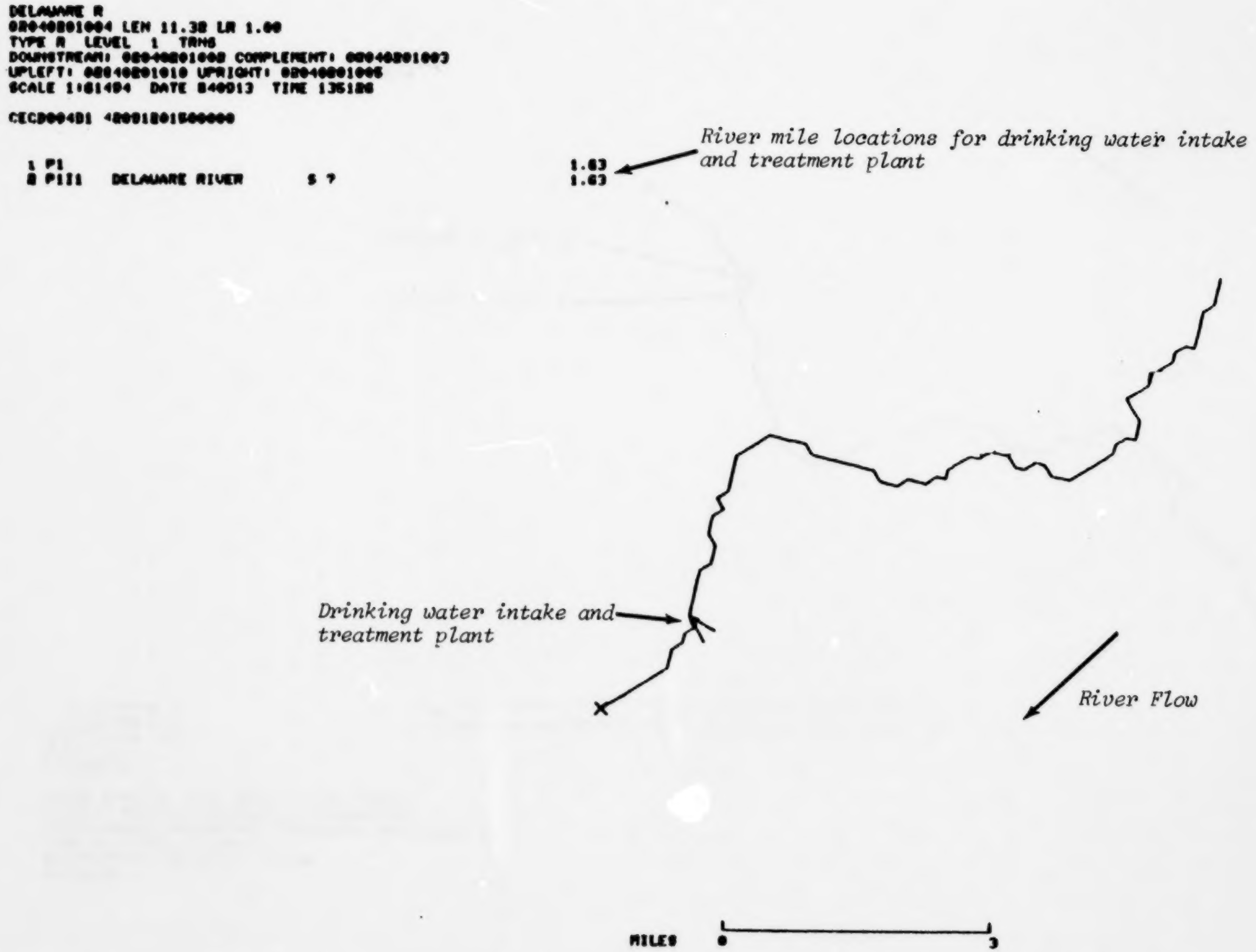
Figure 9. WQAB Sitehelp Example of River Mile Location for REACH 02040201004



```
DELAWARE R
02040201004 LEN 11.32 LR 1.00
TYPE R  LEVEL  1  TRNS
DOWNSTREAM: 02040201002 COMPLEMENT: 02040201003
UPLEFT: 02040201010 UPRIGHT: 02040201005
SCALE 1:81404  DATE 840913  TIME 135063

NJ0005142
Company A
BURLINGTON /TWP/
  1 DELAWARE R                        Y   1.81
  2 DELAWARE R                        Y   1.54
```

River mile location for Pipe #2
River mile location for Pipe #1
Company A Pipe #2
Company A Pipe #1
River Flow
MILES
0
3

Figure 10. WQAB Sitehelp Display of Company A Discharge Pipes



```
DELAWARE R
02040201004 LEN 11.38 LR 1.00
TYPE R  LEVEL  1  TRMS
DOWNSTREAM: 02040201008 COMPLEMENT: 02040201003
UPLEFT: 02040201010 UPRIGHT: 02040201006
SCALE 1:81494  DATE 840913  TIME 135128

CECD004D1 42091201500000

  1 P1                                                   1.63
  8 P111   DELAWARE RIVER      S 7                       1.63
```

River mile locations for drinking water intake and treatment plant

Drinking water intake and treatment plant

River Flow

Figure 11. WQAB Sitehelp Display of Drinking Water Intake for Water Supply Company B

```
STARTING POINT OR END:  P=NJ0005142
UP/DOWN(U/D)?  D
LEVEL=+0
MILES=10
REPORT ON DRINKS(Y/N)?  Y
DATE 840925    TIME 120747
        6 REACHES
       29 PIPES
        3 PLANTS-INTAKES-SOURCES
DETAIL(Y/N)?  Y

    0.00  02040201004/000.00  TYPE R  LEV 1  LENGTH  11.30  NAME DELAWARE R
                             15 DISCHARGES
     0.00 PIPE  1 NPDES# NJ0005142 Company A                  ON   FLOW(TGD)  206.00 -P SIC  2865   -1   -1
     0.18 DRINK PA1090001 Water Supply Company B     30000 N   5200 TGD TYPE P1     BRISTOL TREATMT PLT  SOURCE ?
     0.18 DRINK PA1090001 Water Supply Company B.    30000 Y      5 TGD TYPE P111   DELAWARE RIVER       SOURCE S
     0.27 PIPE  2 NPDES# NJ0005142 Company A                  ON   FLOW(TGD)  541.00 -B SIC  2865   -1   -1
     0.27 PIPE  1 NPDES# PA0045543 BROWN CO SPECIALTY PROD DION   FLOW(TGD)  800.00 -P SIC  2649   -1   -1
     0.27 PIPE  3 NPDES# PA0045543 BROWN CO SPECIALTY PROD DION   FLOW(TGD)  220.00 -O SIC  2649   -1   -1
     0.27 PIPE  4 NPDES# PA0045543 BROWN CO SPECIALTY PROD DION   FLOW(TGD)  400.00 -C SIC  2649   -1   -1
     0.92 PIPE  1 NPDES# PA0037273 FEDERAL STEEL CORP         ON   FLOW(TGD)    8.00 -P SIC  3312   -1   -1
     1.03 PIPE  1 NPDES# PA0050369 UNITOG COMPANY             OFF  FLOW(TGD)   30.00 -C SIC  7216   -1   -1
     1.43 PIPE  1 NPDES# PA0013161 MIDDLETOWN TOWNSHIP OF     OFF  FLOW(TGD)    3.00 -P SIC  4941   -1   -1
     1.43 PIPE  2 NPDES# PA0013161 MIDDLETOWN TOWNSHIP OF     OFF  FLOW(TGD)    3.00 -P SIC  4941   -1   -1
     1.55 PIPE  1 NPDES# PA0012769 ROHM & HAAS CO BRISTOL PLAON   FLOW(TGD)  220.00 -C SIC  2821 2869   -1
     1.55 PIPE  2 NPDES# PA0012769 ROHM & HAAS CO BRISTOL PLAON   FLOW(TGD) 2800.00 -C SIC  2869   -1   -1
     1.55 PIPE  3 NPDES# PA0012769 ROHM & HAAS CO BRISTOL PLAON   FLOW(TGD)   30.00 -C SIC  2821   -1   -1
     1.55 PIPE  4 NPDES# PA0012769 ROHM & HAAS CO BRISTOL PLAON   FLOW(TGD)   40.00 -C SIC  2821   -1   -1
     1.55 PIPE  5 NPDES# PA0012769 ROHM & HAAS CO BRISTOL PLAON   FLOW(TGD) 1290.00 -C SIC  2821   -1   -1
     1.55 PIPE  6 NPDES# PA0012769 ROHM & HAAS CO BRISTOL PLAON   FLOW(TGD) 1620.00 -P SIC  2869 2821 2879
     1.81 GAGE WEG02040201004       ?                        STCO    -1 DA      -1 ?   MF 13396 LF  2458

    1.81  02040201002/000.00  TYPE R  LEV 1  LENGTH   3.20  NAME DELAWARE R
                             10 DISCHARGES
     2.78 PIPE  1 NPDES# NJ0005002 P.S.G.&E.                  ON   FLOW(TGD)    1.00 -B SIC  4931   -1   -1
     2.78 PIPE  2 NPDES# NJ0005002 P.S.G.&E.                  ON   FLOW(TGD)49000.00 -C SIC  4931   -1   -1
     2.78 PIPE  3 NPDES# NJ0005002 P.S.G.&E.                  ON   FLOW(TGD)  200.00 -B SIC  4931   -1   -1
     2.92 PIPE  1 NPDES# NJ0021709 BURLINGTON TWP MAIN STP    OFF  FLOW(TGD)  750.00 -P SIC  4952   -1   -1
     2.92 PIPE  1 NPDES# NJ0024660 CITY OF BURLINGTON         ON   FLOW(TGD) 1400.00 -P SIC  4952   -1   -1
     3.31 PIPE  4 NPDES# NJ0005002 P.S.G.&E.                  ON   FLOW(TGD)86400.00 -C SIC  4931   -1   -1
     3.31 PIPE  1 NPDES# NJ0005690 P.S.E. & G.                ON   FLOW(TGD)86400.00 -B SIC  4931   -1   -1
     3.31 PIPE  1 NPDES# PA0026450 LOWER BUCKS COUNTY JT. MUNON   FLOW(TGD) 3000.00 -P SIC  4952   -1   -1
     3.44 PIPE  1 NPDES# NJ0004391 TENNECO PLASTICS DIV       OFF  FLOW(TGD) 2290.00 -P SIC  2821   -1   -1
     3.44 PIPE  2 NPDES# NJ0004391 TENNECO PLASTICS DIV       OFF  FLOW(TGD)  180.00 -P SIC  2821   -1   -1
     5.01 GAGE WEG02040201002       ?                        STCO    -1 DA      -1 ?   MF 13496 LF  2463

    5.01  02040201001/000.00  TYPE R  LEV 1  LENGTH   2.20  NAME DELAWARE R
                              3 DISCHARGES
     6.09 PIPE  1 NPDES# NJ0027481 BEVERLY SEWERAGE AUTHORITYON   FLOW(TGD)  610.00 -P SIC  4952   -1   -1
     6.34 PIPE  1 NPDES# PA0011932 DUPONT DENEMOURS & CO I&B ON   FLOW(TGD) 2170.00 -P SIC  2819   -1   -1
     6.49 PIPE  1 NPDES# PA0011347 PENNWALT CORPORATION - CCRON   FLOW(TGD)   25.00 -P SIC  2869   -1   -1
     7.21 GAGE WEG02040201001       ?                        STCO    -1 DA      -1 ?   MF 13884 LF  2479
```

Figure 12. Example Pathscan Report

was designated as the starting point of the investigation (It it is possible, however, to use other designators such as REACH #, Dunn & Bradstreet #, Needs #, USGS Gage # or FRDS #). The report presents information on REACH 02040201004 and two reaches downstream and lists the stream flow gages on each reach, showing the mean annual and 7-Q-10 flow rate (in CFS). It also includes other industrial facilities in various SIC categories with information on wastewater pipes) flow rate and type of wastewater (cooling, process, or both). Drinking water intake points are also listed, including the name, the daily withdrawal, and the population served. Also listed for each drinking water facility is the EPA Office of Drinking Water FRDS identification number. This FRDS number may be used for cross referencing of information contained in the Office of Drinking Water's computer data base, the significance of which will be discussed in the subsequent section[1].

The final type of retrieval option or interactive program involves the identification of surface drinking water supplies that may be contaminated by leachate or runoff from a waste disposal site, a spill, or from a nonpoint source (e.g., combined sewer overflow, urban and agricultural storm water runoff). In the HLDF system, there are no data files that provide the location of these contamination sources. The location of waste disposal sites can be found in data bases discussed in Volume 3 of this methods series (i.e., Methods for Assessing Exposure from Disposal of Chemical Substances). Information on transportation-related hazardous materials spills is discussed in Volume 9 of this series (i.e., Methods for Assessing Exposure to Transportation Related Spills). Nonpoint sources of contamination must be located geographically according to political boundaries (e.g., state, county, city) or according to U.S. Geological Survey hydrologic unit basins. In all cases, the location of the contamination source must be used to identify the receiving water body(s) contaminated and the respective REACH number(s). The REACH number(s) of the contaminated receiving water body(s) is required to identify raw drinking water intake points.

The first eight digits of the REACH number are obtained from U.S. Geological Survey Hydrologic Unit Maps. Hydrologic Unit Maps delineate river basins in the U.S. A hydrologic unit map has been prepared for each of the 50 states at a cost of $2.25 each. They can be purchased at the USGS Sales Office in Reston, Virginia, for all 50 states. The USGS Branch of Distribution in Arlington, Virginia, sells maps for states east of the Mississippi River and the distribution office in Denver, Colorado, sells maps for states west of the Mississippi River. The mailing address of each office is as follows:

---

[1] Occasionally, an FRDS number for a particular utility differs between the two data bases because the state may change FRDS numbers.

U.S. Geological Survey
National Cartographic
Information Center
507 National Center
Reston, VA. 22092

U.S. Geological Survey
Branch of Distribution
1200 South Eads Street
Arlington, VA. 22202

U.S. Geological Survey
Branch of Distribution
Box 25286, Federal Center
Denver, CO. 80225

To obtain the first eight digits of the REACH number, the investigator must locate the site or area under study on the pertinent state hydrologic unit map and record the hydrologic unit number of the basin in which the site or area is located. The EPA segment number, or last three digits of the REACH number, may be obtained from a catalog (unpublished) of REACH maps (organized by hydrologic units) available in the Water Quality Analysis Branch Office of EPA-MDSD. Information on segment numbers and REACH maps may also be obtained by contacting Mr. Robert C. Horn, Environmental Engineer, Monitoring Branch of EPA-MDSD. REACH numbers should be obtained for the water body segment of interest and for all downstream segments also possibly contaminated by the chemical substance of interest.

Once the REACH numbers have been identified, water supplies on or downstream of the receiving water body may be identified by several of the previously discussed HLDF system's interactive programs. In particular, a Pathscan or HYDRO retrieval will identify drinking water intakes and thus drinking water supplies on or downstream of the point where contamination occurs.[1] HYDRO retrievals, as detailed in USEPA (1981a), may be restricted to include only drinking water intakes, or any combination of industrial and POTW discharge pipes, gages including flow data, and water quality monitoring stations. If the reach under study is one of the 400 BAT impacted receiving streams or is the site of an industry with frequent occurences in the Canonical Environments Data Base, as previously discussed, the HYDRO or PATHSCAN retrieval will illustrate the river mile locations of all data points. This will permit the determination of distances between the point of chemical discharge and drinking water intakes.

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[1] In most cases, the locational data is dependable but exceptions do exist, and this possibility should be taken into account when making an identification, especially when a facility serving less than 25,000 people is involved.

The interactive program SITEHELP may also be used for a detailed examination of single reaches. As previously described, SITEHELP allows the user to display the reach under study on a CRT terminal. SITEHELP also allows the user to assign river mile locations to all data points on the reach. SITEHELP procedures that are "user friendly" have recently been developed for non-graphic (standard hard copy) as well as graphic (CRT) terminal users, by the Water Quality Analysis Branch of EPA-MDSD.

The previous discussions on interactive programs of the HLDF system are presented to aid the investigator or exposure assessment team in determining the type of retrievals that will assist in identifying contaminated drinking water supplies. Retrievals may be performed by the investigator, or retrievals may be requested from the Water Quality Analysis Branch of EPA-MDSD. Self-performed retrievals are preferred because they allow the user much more flexibility and control in acquiring needed information. Before retrievals are performed, however, the procedures described in USEPA (1981a) should be reviewed.

The Water Qualtiy Analysis Branch of EPA-MDSD continues to enhance the "user friendly" procedures to meet the needs of the user environment. In addition, "special" retrievals using newly developed software packages are also possible to assist in retrieving data from the HLDF system.

3.1.2 Federal Reporting Data System (FRDS)

FRDS is an information management system maintained by the EPA Office of Drinking Water. FRDS contains inventory data as well as the compliance status of each public water supply in the U.S. and territories. The data base is updated yearly with data collected by the individual states; as such, the data represent the most up-to-date public water supply information available.

Four types of data are collected by FRDS, based on regulatory reporting requirements (Mark 1980):

1. Inventory. This includes facility name and address, public water supply capacity, source information (surface and ground) including name and location, the number of wells if applicable, monitoring requirements, population served, number of service connections, and the treatment techniques used.

2. Violation. This includes data pertaining to non compliance with EPA or state standards by a specific water supply.

3. Variance and exemption. This includes data pertaining to authorized exceptions to the standards which are granted to a specific water supply.

4. Enforcement action. This includes information pertaining to action taken against a public water supply.

In addition, summary statistics for each state are generated and maintained within the FRDS data base.

Unlike the WSDB, FRDS does not include REACH numbers and is, therefore, not exactly hydrologically linked to any other EPA surface water data bases. Retrievals are possible, however, by hydrologic unit code and according to geographic or political boundaries but not by river, lake, stream, or water supply name. When identifying surface water supplies potentially contaminated with a chemical substance, FRDS is a supplementary data source. FRDS retrievals may be used to confirm or add information to that obtained from WSDB. The major application of FRDS is to aid in identifying potentially contaminated ground water supplies and in supplying treatment techniques for specifically identified drinking water utilities identified in HLDF system retrievals. The use of FRDS for identifying potentially contaminated ground water supplies is discussed in the following subsection. Section 5 discusses the use of FRDS for obtaining information on treatment procedures.

For additional information on FRDS including retrieval requests, inquiries should be directed to:

Mr. Avrum W. Marks
Manager-Computer Systems Staff
U.S. Environmental Protection Agency
Office of Drinking Water
401 M Street, S.W.
Washington, D.C. 20460
(202) 382-5513

3.2 Identification of Ground Water Supplies

Because the problem of ground water contamination has only recently received much attention, no computerized data bases yet exist such as those for surface waters (e.g., WSDB). Nearly all of the available information is in text form. There is much information on a regional, state, and county basis; unfortunately, the sources and origins of the data are not uniform or interrelated. The USGS has, however, begun a large coordinated series of ground water investigations - Regional Aquifer Systems Analyses (RASA). This program is a systematic effort to characterize 28 to 29 hydrogeological regions which make up most of the contiguous U.S. (Bennett 1979). The overall objective of RASA is to assemble specific information on aquifers within the regions, especially those used as drinking water sources, such that predictive capabilities can be developed in case of contamination or overuse. Because RASA was only conceived in 1978 and is not expected to be fully completed until 1989, it is of minimal use for present exposure assessments.

This section will discuss data sources that will provide locational information on aquifers. Exposure assessments can essentially take on two forms -- site-specific and nonsite specific; therefore, the discussion has been divided into two parts. The first identifies data sources that would best suit a site-specific study (Section 3.2.1), and the second identifies sources for nonsite-specific studies (Section 3.2.2). The investigator might also find use for the information sources described in Section 3.2.1 for nonsite-specific studies.

3.2.1 Identifying Site-Specific Ground Water Supplies

Characterization of a chemical substance's production, use, and disposal or "materials balance" will determine the sources and pathways of entry of the substance to the environment. The nature of a chemical substance's use in industry as well as its production history are required to determine the modes of its disposal and subsequent discharge to drinking water supplies. Guidelines for performing a source analysis or materials balance can be obtained in JRB (1980) and in Volume 2 of this methods report series (i.e., Ambient Volume).

The major sources of ground water contamination in site-specific studies will be landfills, surface impoundments (e.g., ponds, lagoons), and deep-well injections (Note: agricultural chemicals and leaking above- and underground storage tanks can also be a significant source of groundwater contamination). Volume 3 of this series (i.e., Disposal Volume) discusses the characteristics of each and the methods for assessing the effects on aquifers. This effort requires information on the locations of the chemical's disposal sites.

This section will describe information sources that will aid in determining whether one of the above disposal practices, in a site-specific area, poses a threat to ground water, and whether the aquifer is used as a drinking water source.

Determination of a disposal site's proximity to an aquifer may be accomplished by the use of state ground water assessments. These ground water assessments are usually published on a county basis by agencies such as state water control boards and departments of natural resources (e.g., Virginia 1978, Illinois 1968). The reports characterize the physical conditions (e.g., hydrology, climate, soils), hydrogeology (e.g., rock formations, ground water location and movement), quality of the water (e.g., pH, total dissolved solids, bacteria), uses (e.g., large withdrawals, domestic wells), problems (e.g., depletion, deterioration), and recommendations for future usage. This information may then be used to assess the potential hazard of disposed chemicals to ground water supplies based on the locales of the disposal site and aquifer. The disposal site need not be located directly above an aquifer to pose a threat. Subsurface lateral movement of water can extend the infiltration zone beyond the surface area directly above the aquifer. The information in these reports is also needed for models which simulate contaminant transport in subsurface waters (see Subsection 4.3).

The USGS's water resources investigations include studies of ground water resources for each state on a county basis (e.g., USGS 1976a) for most major counties that utilize ground water resources. They are similar to the state reports previously mentioned. The USGS reports define the geologic and hydrologic characteristics of the region. Maps depicting the size, shape, and depth of aquifers as well as graphs and diagrams illustrating the hydrogeology are included. Information on water resources investigations for a specific locale can be obtained by contacting the respective state or district USGS office or from the following:

Chief Hydrologist
U.S. Geological Survey
420 National Center
Reston, Virginia 22092

Site-specific ground water information can also be acquired using the National Water Data Exchange (NAWDEX). NAWDEX is an interagency program managed and coordinated by the USGS that aids in identifying, locating, and acquiring water related data. It serves as a means of exchanging water data among nearly 150 organizations including federal, state, and local governments and interstate, academic, and private sectors. Information is accessible at the Program Office, located within the Water Resources Division of the USGS in Reston, Virginia, and at 60 assistance centers located throughout the country. Most of the information centers have hydrologists or other specialists who can aid in identifying data sources (Edwards 1980).

In addition to information indices, NAWDEX centers also have access to the USGS's Water Data Storage and Retrieval System (WATSTORE) (Edwards 1980). WATSTORE is the data bank for all the information collected by the

USGS at its sampling sites throughout the country (Showen 1978). WATSTORE contains a Water Quality File which offers chemical, physical, biological, and radiochemical data on approximately 5,800 ground water quality wells. Data entered in the Water Quality File are also entered in the EPA's STORET System. A ground water Site Inventory File is also contained within WATSTORE. This file comprises data on wells, springs, and other sources of ground water. The data include site location and identification, geohydrologic characteristics, well construction history, and one-time field measurements such as water temperature, pH, and hardness. The data currently cover approximately 600,000 wells (Edwards 1980).

The Federal Reporting Data System (FRDS) should be used to determine whether an aquifer is being used as a drinking water supply. It is the principal data source for identifying either public or private drinking water utilities or companies that use ground water as a raw water supply. The retrievals from FRDS are available on a county or state basis. The locations of the pumping wells are reported; however, when the total number of wells is greater than three, only the geographical center of all the wells is reported. In such cases where it is uncertain as to which aquifer a well may be pumping from, available county reports previously mentioned usually contain information on the usage levels from the aquifers; this information can then be used to determine whether an aquifer is being used for drinking water.

3.2.2 Identifying Non-Site-Specific Ground Water Supplies

Exposure assessments that deal with chemicals of a ubiquitous nature will require generalized information on aquifers. Before obtaining that information, however, the source assessment should have characterized the chemical as to where (e.g., state, region) it is of most concern and by what mode it may contaminate ground water. Examples of chemicals that would require a non-site-specific investigation are household products that might be discarded as solid waste and destined to a landfill, or those that might be discarded via a septic tank. In both instances, there is potential for the chemical to leach into ground waters.

This section describes information sources that will aid in identifying regional aquifer systems and ground water usage levels that would be appropriate for non-site-specific assessments.

USGS characterizes the nation's ground waters in a series of summary appraisals of 22 hydrogeological regions of the U.S. Each region is characterized in a separate document, and the entire series is listed under Geological Survey Professional Papers - 813. The documents describe the major aquifers in the region and their respective geological types (i.e., consolidated or unconsolidated). In addition, the documents discuss:

- Populations within the region
- Major economic industries
- Ground water quantity
- Ground water usage (private and industrial)
- Ground water problems
- Conjunctive uses of ground water and surface water
- Ground water studies taking place and the need for continued investigations.

Each document also describes the aquifers on a state basis for those states within the region. Maps depicting the location, size, and type of aquifers in the states are also included in the reports. The series is currently being updated from the 1978 reports.

The U.S. Water Resources Council, in a four-volume report (USWRC 1978), assessed the nation's water supplies on a regional and subregional basis. The first three volumes summarize the data, and the fourth volume comprises the series of regional reports. The reports contain much the same information as the USGS appraisal reports. The ground water information deals mostly with the volume and daily withdrawal from the aquifers. The report discusses the problems of overdraft and contamination of aquifers, along with the problems associated with recharging of the ground water. The report also estimates the use of ground waters for the year 2000 for each region.

There were no data sources found that report the percentage of ground water used for drinking water. Solley et al. (1983) report the percentage of total water used that is ground water for each state (Table 6) and the amounts withdrawn. In addition, they characterize the geographical use of surface and ground waters throughout the country.

Table 6. Percentage of Ground Water Use of Total Water Use For Each State in 1980

State	Percent
Alabama	3
Alaska	22
Arizona	53
Arkansas	25
California	39
Colorado	18
Connecticut	4
Delaware	7
Florida	18
Georgia	17
Hawaii	32
Idaho	35
Illinois	5
Indiana	9
Iowa	18
Kansas	84
Kentucky	5
Louisiana	14
Maine	5
Maryland	2
Massachusetts	5
Michigan	6
Minnesota	22
Mississippi	43
Missouri	7
Montana	2
Nebraska	60
Nevada	20
New Hampshire	7
New Jersey	7
New Mexico	46
New York	5
North Carolina	10
North Dakota	9
Ohio	7
Oklahoma	61
Oregon	16
Pennsylvania	1
Rhode Island	7
South Carolina	4
South Dakota	48
Tennessee	5
Texas	38
Utah	22
Vermont	85
Virginia	4
Washington	9
West Virginia	4
Wisconsin	11
Wyoming	35

Source: Solley et al. (1983).

4. QUANTIFICATION OF RAW WATER CONCENTRATIONS OF CHEMICAL SUBSTANCES

The next step in the drinking water exposure assessment method is the quantification of the chemical substance in raw water supplies, or the concentration of the substance in water immediately prior to withdrawal for treatment. Quantification may be accomplished in two ways:

- Acquisition of waterborne monitoring data for the chemical substance.
- Estimation of the concentration based on the chemical-physical properties and environmental fate of the substance and the hydrological factors that determine a substance's concentration in water supplies.

Monitoring data are often limited or nonexistent. Estimation, therefore, becomes the only practical way to quantify the concentration where monitoring data are not available. The purpose of this section is to catalog and describe: (1) sources of information and data bases from which the investigator or exposure assessment team can obtain monitoring data (Subsection 4.1), and (2) the methods or tools (e.g., models) that can be used to estimate the concentration of chemical substances in surface water (Subsection 4.2) and ground water (Subsection 4.3).

4.1 Monitoring Data

Monitoring data, when available, will generally provide the most accurate quantification of the concentration of a chemical substance in raw water supplies. It is therefore the preferred information resource in this step of the drinking water exposure assessment process. However, monitoring data must be carefully evaluated for accuracy, precision, and representativeness, for it can often be misleading. Common problems include: outdated results, data that reflect discontinued practices or emissions, varying analytical methods and reported detection limits, and questionable sampling and analysis QA/QC. The quality of available monitoring data, therefore, must be determined and its limitations reported in the exposure assessment. Section 4 of Volume 2 of this methods series (i.e., Ambient Volume) and the Appendices to Volume 2 provide details on the sources of monitoring data. This section will briefly review the sources of monitoring data that are applicable for a drinking water exposure assessment.

Monitoring data for a chemical substance in ambient water or, preferably, raw drinking water supplies may be obtained from the following three major information resource categories:

1. Federally-funded data management systems or computerized water quality data bases.

2. Published scientific literature.

3. Unpublished information (e.g., water utility in-house monitoring programs), including government (e.g., federal, state) task and project reports.

A comprehensive drinking water exposure assessment should access the available monitoring data in each of these categories. Each of these categories is described below.

There are two major federally funded water quality data bases. These are the EPA-supported STORET data base and the USGS supported National Water Data Storage and Retrieval System (WATSTORE). STORET is updated with the data contained in WATSTORE on a yearly basis, and is, therefore, the most comprehensive monitoring data base available. The data in STORET are also available via a greater number of retrieval options. In particular, STORET monitoring stations and data may be plotted on maps in relation to water bodies, a retrieval capability that is not available via WATSTORE. Both STORET and WATSTORE are discussed in detail in Appendix A of Volume 2 of this series.

The quality of STORET and WATSTORE data, particularly data summaries, should be carefully evaluated before use in any exposure assessment. Problems frequently encountered with STORET and WATSTORE summary data include:

- Data source unknown. Summary retrievals for pollutants do not include station location information. This problem may be overcome by requesting a station inventory along with all summary retrievals.

- Quality of data unknown. Sampling and analytical procedures are not reported in data retrievals. The QA/QC procedures to provide defensible data are, therefore, unknown. Station inventories will provide leads to obtain information on data QA/QC.

- Unknown and/or varying detection limits. Because of varying analytical detection limits, problems frequently arise in interpreting non-detections in relation to detected values. Typical STORET summaries set all non-detections equal to the detection limit when computing statistics. Other operational approaches (e.g., eliminating all non-detections) are possible. Remark codes, which describe the data detection limitations, should be carefully reviewed before inclusion of data in the exposure assessment process.

- Data may be outdated, often reflecting results of discontinued practices. Unless time (i.e., specific years of data interest) limitations are specified, STORET and WATSTORE retrievals will provide all reported results for the pollutants of interest. Changes in analytical and sampling procedures, pollutant discharge control measures, and other related historical factors that affect reported results should be reviewed when STORET data are evaluated. Retrievals should be restricted to the time period that best represents current environmental conditions.

Users of on-line monitoring data, such as STORET and WATSTORE, should be aware of these problems and deal with them accordingly before data inclusion into an exposure assessment for a chemical substance.

The published scientific literature includes professional and trade journals, government reports, books, and symposium proceedings. Information on specific chemicals may be identified by a number of bibliographic on-line search systems. The DIALOG and ORBIT search systems, in particular, are very useful for identifying literature that may possibly contain monitoring data. These and other search systems are discussed in the Information Resource Matrix, Appendix A of Volume 2 of this series.

Unpublished information including government task and project summaries, as well as ongoing research projects that may contain monitoring data for a chemical substance of interest, may be obtained from a number of sources. The National Water Data Exchange (NAWDEX), a computerized data base maintained by the U.S. Geological Service, is the most comprehensive information resource for identifying or locating possible sources of unpublished data. NAWDEX's primary objective is to assist users of water data in the identification, location, and acquisition of needed data. For example, NAWDEX can be used to identify water data available in a geographic area and to locate the names and addresses of organizations from which the identified data can be obtained. NAWDEX is not a repository of water data; however, it does have direct access to some large water data bases such as STORET and WATSTORE. Further information on NAWDEX is available in the Information Resource Matrix or by contacting:

National Water Data Exchange (NAWDEX)
U.S. Geological Survey
421 National Center
Reston, VA 22092
Telephone: (703) 860-6031

Other sources of unpublished data which may prove useful are universities; often those with special geographic ties to a chemical's production or use conduct ongoing research efforts in related special areas. Unpublished task or project reports prepared by or for government agencies or divisions of government agencies may contain pertinent monitoring data. A list of government agencies that may have performed monitoring surveys to support the development of policies or regulations for a chemical substance or group of substances should be prepared; those agencies should then be contacted in the course of preparing the exposure assessment. In particular, the EPA Office of Drinking Water should be consulted for available unpublished monitoring data. State agencies with regulatory control of drinking water supplies in specific geographic areas of interest for a chemical substance may also have unpublished monitoring data. Finally, drinking water utilities or treatment plants where contamination is known or suspected may monitor the quality of their raw water supplies. The Information Resource Matrix, Appendix A of Volume 2, also discusses additional sources of unpublished monitoring data.

4.2 Estimation of Concentration in Surface Water

The concentration of a chemical substance in surface water can be estimated by either of two procedures:

1. Conservative estimate - simple dilution of the substance discharged by surface flow, assuming no other mechanism of attenuation (fate or transport).

2. Modeling - concentration calculated using an appropriate fate and transport model.

The procedure chosen for use depends on the level of detail desired and the amount of time and financial resources available. Conservative estimates will obviously provide a less accurate concentration. The procedure may, however, be used as a screening evaluation of possible surface water concentrations. It may also be used when either the time or data necessary to make an accurate estimate is limited. Modeling requires a good understanding of models and their input data requirements. Modeling is also much more labor-, data-, and time-intensive. The following subsections provide details on the two estimation procedures.

4.2.1 Conservative Estimates

Conservative estimation assumes a constant wastewater discharge and simple dilution of the discharged substance in the receiving stream. The ambient background concentration of the substance is assumed to be equal to zero. Attenuation of the substance due to its fate and transport is not considered in the calculation and complete mixing of the chemical in the receiving water is assumed. As such, the procedure provides a conservative estimate of the concentration of the substance in the receiving stream or drinking water supply.

There are two approaches for making conservative calculations of the concentration of a chemical substance in receiving water. The first approach is for assessments performed on specific plants and receiving streams and requires actual flow rates for the receiving water body. The second or statistical approach is used in situations where the sources of contamination are too numerous to deal with individually. This approach relies on the use of mean and low (i.e., 7-Q-10) stream flow rates for an industrial discharge category of interest. The low stream flow rate represents the minimum average dilution that may be expected to occur over a consecutive 7 day period with a recurrence interval of 10 years. Although there is no strict water quality or technical basis for doing so, the 7-Q-10 is the most commonly used design stream low flow for waste load allocation analyses (surface water concentrations calculated under low flow conditions are compared to acute ambient water quality criteria or other toxicity data to determine potential for environmental impacts). Use of the site-specific and generic approaches are described in the following paragraphs.

Calculation of potential surface water concentrations in site-specific assessments relies on three pieces of information: the flow rate of the discharge stream, the concentration of the chemical substance in the discharge stream, and the receiving water flow rate (both mean and low flow). Alternatively, when the wastewater flow rate and concentration of the chemical substance of interest are not available, the total daily discharge of the substance (e.g., mass/day) may be used to conservatively estimate receiving water concentrations. The concentration of the substance in the discharge stream and the flow rate of the discharge stream or, alternatively, the daily mass loading, will have been determined or estimated as a result of the materials balance performed for the substance and are not within the scope of work of this volume (See JRB 1980 and Volume 2, Section 2 (i.e., Ambient Volume) and Volume 3, Sections 2 through 7, of this series (i.e., Disposal Volume)).

The mean and low flow rate for a specific water body can be obtained from a number of information sources. As discussed in Subsection 3.1, the integrated approach (HYDRO, SITEHELP, IHSBRWSE, AND RCHDAT) to locating industrial sources of discharge, receiving waters, and drinking water supplies will also identify the flow gages and the mean annual and 7-day-10-year (7-Q-10) low flow rates for the period of record. Flow data may also be accessed by using EPA-MDSD's GAGE File. The REACH number (USGS 8-digit hydrologic unit number plus the 3-digit EPA segment number) may be used to identify gages and obtain the mean annual and 7-Q-10 flow for a specific water body. The flow rates obtained from these types of retrievals are all reported on an annual basis for the period of record.

Flow rates may also be calculated for shorter periods of record as well as for time periods within a year (e.g., month, season). These hydrologic statistics can be computed by using the EPA STOrage and RETrieval (STORET) Flow Data File (FDF). Information on STORET-FDF, including the various programs available to STORET users for analysis of flow samples, is available in the Handbook of the Water Quality Control Information System STORET-Part FL (Flow Data File) (USEPA 1981b). Inquiries and specific retrievals should be directed to EPA-STORET User Assistance, in Washington, D.C.

Finally, stream flow data can be accessed manually by referring to the USGS reports published annually on a state-by-state basis (e.g., "Water Resources Data for Virginia, Water Year 1980"). Locations of gaging stations are provided in a map in the front of each report, and average, high, and low flows are summarized for each station on an annual basis and over the period of record. Daily flows are also provided, allowing calculation of seasonal averages.

Following acquisition of the receiving water flow rate, the concentration of the chemical substance in the receiving water body may be calculated using a Stream Dilution Factor (SDF) or by simply diluting the daily load by the receiving stream flow rate. The SDF is the ratio of receiving water flow rate to discharge stream flow rate, and should be calculated for the mean receiving water flow rate and the 7-Q-10 flow rate. The concentration of the chemical substance in the receiving water body, using both SDFs, is calculated as follows:

$$\text{Receiving Stream Concentration} = \frac{\text{Effluent Concentration}}{\text{SDF}}$$

The following examples describe the site-specific approach for calculating the receiving water concentration of a chemical using either a SDF or simply diluting a daily mass loading:

Calculation of In-Stream Pollutant Concentration using an SDF: Evaluation of the process chemistry for producing chemical A at an organic chemical manufacturing plant located in Beaumont, Texas, results in a wastewater concentration estimate of 1560 ug of A/l. Using the procedures discussed in Section 3.1, the following information was obtained:

Facility name and location: Plant D; Beaumont, Texas
Receiving stream name: Neches River
REACH #: 12020003/001
Facility flow (MGD): 5.40
Receiving stream mean flow (MGD): 5,280
Receiving stream low flow (MDG): 186

The stream dilution factors (SDFs) can be calculated from the above information as follows (Note: This example problem assumes that the receiving stream flow rate is obtained from a gaging station downstream from the discharge and includes the flow contribution from the discharge. If the gaging station were upstream from the discharge, the SDF would have to take into account the flow contribution of the discharge to the stream flow assuming the discharge flow is significant in relation to the stream flow.):

$$\text{Mean SDF} = \frac{\text{Mean stream flow}}{\text{Facility flow}} = \frac{5{,}280}{5.40} = 978$$

$$\text{Low SDF} = \frac{\text{Low stream flow}}{\text{Facility flow}} = \frac{186}{5.40} = 34.4$$

Finally, the chemical A in-stream concentration can be calculated using the following equations:

$$\text{Chemical A In-Stream Concentration (Mean Flow)} = \frac{\text{Chemical A effluent conc.}}{\text{Mean SDF}}$$

$$= \frac{1{,}560}{978} = 1.60 \text{ ug/l}$$

$$\text{Chemical A In-Stream Concentration (Low Flow)} = \frac{\text{Chemical A effluent conc.}}{\text{Low SDF}}$$

$$= \frac{1{,}560}{34.4} = 45.3 \text{ ug/l}$$

Calculation of In-Stream Pollutant Concentration Using a Daily Mass Loading: The reported or estimated* daily wastewater loading during the production or industrial use of chemical B at an organic chemical manufacturing plant located in York, New York is 10 kg/day. Using the procedures discussed in Section 3.1, the following information was obtained:

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*When plant specific data are not available, annual waterborne emissions can be estimated using generic emission rates. Waterborne emissions during organic chemical manufacturing average 0.4 percent of production/use (see Volume 2 of this Method series for more detailed information).

Facility name and location:	Plant X, York, New York
Receiving stream name:	Genessee River
REACH #:	04130003/013
Receiving stream mean flow (MGD):	1125
Receiving stream low flow (MGD):	55

Chemical B in-stream concentration can be calculated as follows:

$$\text{Mean receiving water concentration} = \frac{\text{Daily load (mass/day)}}{\text{Mean stream flow (volume/day)}}$$

$$= \frac{\text{10 kg/day}}{\text{1125 MGD} \times \text{3.79 l/gal}}$$

$$= 2.3 \times 10^{-9} \text{ kg/l or 2.3 ug/l}$$

$$\text{Low receiving water concentration} = \frac{\text{Daily load (mass/day)}}{\text{Low stream flow (volume/day)}}$$

$$= \frac{\text{10 kg/day}}{\text{55 MGD} \times \text{3.79 l/gal}}$$

$$= 4.8 \times 10^{-8} \text{ kg/l or 48 ug/l}$$

The second approach to calculate the concentration of a chemical substance in receiving water bodies that are too numerous to work with individually relies on the basic principles previously discussed and on statistical mean and low flows for an industrial category. Table 7 summarizes the mean pipe flow and the mean and 7-Q-10 receiving stream flow rates for the major industrial categories. Data are presented both for direct industrial discharge and indirect discharge (i.e., industrial discharge via a Publicly Owned Treatment Works (POTW)). These data were calculated by comparing the hydrologic location of all industrial dischargers for each specific SIC code, the reported discharge pipe flow rate as recorded in IFD, and the flow data of receiving streams as recorded in the GAGE File. Since the flow data calculated do not fit a normal statistical distribution, they are presented for two percentile ranks, the 10th and 50th. The 50th percentile is the median receiving

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD)		Direct Discharge (MLD)[b]				No. of POTWs	Indirect Discharge (MLD)			
					Mean		Low[c]			Mean		Low[c]	
			10	50	10	50	10	50		10	50	10	50
10	Metal Mining	445	0.003	0.28	5.0	180	0	15	0	0	0	0	0
11,12	Coal Mining	6,794	0	0.095	64	290	0.019	6.0	2	32000	32000	5900	5900
13	Oil and Gas Extraction	390	0	0.19	850	78000	4.5	4000	3	82	82	0	0
14	Nonmetallic Mining	167	0.11	1.9	160	720	1.2	18	3	0	0	0	0
20	Food and Kindred Products	3,166	0.004	0.17	94	540	1.3	29	761	120	1000	0.22	59
201	Meat Products	447	0.008	0.42	92	380	0.71	18	249	110	1700	0.072	84
202	Dairy Products	778	0.008	0.16	75	290	1.2	24	283	130	1300	0.66	85
203	Canned and Preserved Fruits and Vegetables	489	0.038	0.66	100	470	0.83	26	203	110	2600	0.034	120
204	Grain Mill Products	135	0.004	0.19	61	840	0.78	37	87	350	6000	4.6	510
206	Sugar and Confectionary Products	110	0.023	16	180	2300	5.4	110	44	250	1300	7.5	68
207	Fats and Oils	141	0.008	0.57	200	2300	0.70	230	116	180	2200	1.1	140
208	Beverages	224	0.011	0.19	140	1300	1.6	50	212	160	2200	1.7	120
209	Miscellaneous Foods (Seafoods, Ice, Noodles)	822	0	0.026	100	980	5.60	36	138	140	760	2.1	79
21	Tobacco	25	0.015	0.083	70	220	7.3	24	14	40	940	1.4	100
22	Textile Mill Products	638	0.011	0.21	89	470	4.7	47	273	76	700	1.8	78
2211	Board Woven Fabric Mills Cotton	140	0.026	0.20	76	240	3.8	23	33	54	260	2.0	59
226	Dyeing and Finishing Textiles, exluding Wool & Knit Fabrics	77	0.008	0.95	130	640	3.8	66	81	110	750	2.7	69
2261	Fin Board Woven Fab. Cot.	36	0.038	0.82	110	560	2.9	69	24	110	340	3.8	61

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) (continued)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD)		Direct Discharge (MLD)[b]				No. of POTWs	Indirect Discharge (MLD)			
					Mean		Low[c]			Mean		Low[c]*	
			10	50	10	50	10	50		10	50	10	50
2262	Fin Board Woven Fab. of MM fibers and silk	19	0.008	0.95	140	770	13	53	24	140	1400	27	80
2231	Wool Dyeing and Finishing	53	0.11	1.5	140	1300	5.4	110	34	76	700	1.2	45
2271, 2272, 2279	Carpet Dyeing and Finishing	31	0.045	0.30	130	300	13	30	29	96	1800	0	170
225 , 2292	Knit Fabric Dyeing - Finishing	86	0.004	0.11	110	530	6.8	60	64	110	710	1.8	76
24	Lumber and Wood Products except furniture	610	0	0	0	0	0	0	0	0	0	0	0
26	Pulp and Paper	696	0.072	4.9	240	5200	15	560	191	150	2700	3.9	220
2611	Pulp Mills	94	0.16	49.	650	12000	20	1200	13	120	4500	0	320
2621, 2631, 2661	Paper Mills	401	0.21	6.1	270	5700	19	560	86	260	3000	0.85	180
27	Printing	109	0.004	0.049	120	1500	3.7	85	97	23	200	3.9	7.6
28	Chemicals and Allied Products	1,799	0.019	0.95	140	2200	2.8	120	415	14	280	4.1	20
281	Industrial Inorganic Chemicals	541	0.023	0.81	150	2800	4.2	180	89	210	3500	6.1	230
2816	Industrial Pigments	35	0.011	0.95	100	780	2.3	48	15	210	5100	48	1200
2819	Industrial Inorganic Chemicals not Classified	306	0.068	2.0	130	2600	2.7	180	50	260	3500	6.1	230
282	Plastics Materials and Synthetic Resins, Synthetic Rubber, Synthetic and other man-made fiber, except glass	337	0.026	1.4	150	2200	5.4	160	97	130	2200	1.7	140

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) (continued)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD)		Direct Discharge (MLD)[b]				No. of POTWs	Indirect Discharge (MLD)			
					Mean		Low[c]			Mean		Low[c]	
			10	50	10	50	10	50		10	50	10	50
2821	Plastics Materials, Synthetic	262	0.023	1.2	150	2100	4.2	160	78	96	3600	0.13	190
2822	Synthetic Rubber	31	0.11	6.0	82	2100	5.4	22	16	0	0	0	0
2823	Cellulosic Man-Made Fibers	14	0.008	31	100	3100	23	200	2	190	190	3.7	3.7
2824	Synthetic Organic Fibers	28	0.21	2.0	260	2400	12	300	7	130	240	2.7	18
283	Drugs	124	0.023	0.29	160	770	3.5	62	173	210	1300	9.3	140
2831	Biological Products	14	0.023	0.19	220	750	7.3	250	12	160	17000	9.3	2200
2833	Medicinal Chemical and Botanical Products	35	0.10	1.5	280	1200	1.6	61	16	280	720	18	69
2834	Pharmaceutical Preparations	72	0.015	0.16	140	500	0.19	43	53	210	2000	9.0	140
284	Soaps, Detergents, and Cleaning Preparations, Perfumes, and Cosmetics, and other Toilet Preparations	97	0.008	0.15	88	500	0.80	34	82	240	3000	9.0	230
2841	Soap and other Detergents, except Specialty Cleaners	33	0.008	1.1	100	600	0.80	92	46	150	1500	7.4	230
2842	Specialty Cleaning, Polishing, and Sanitation Preparations	24	0.008	0.026	69	530	1.7	31	21	3500	8900	170	2000
2843	Surface Active Agents, Finishing Agents, Sulfonated Oils and Assistants	12	0.008	0.13	21	1300	6.3	150	7	500	780	18	56
2844	Perfumes, Cosmetics, and Other Toilet Preparations	25	0.019	0.091	89	430	0	22	27	340	3000	9.0	87

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) (continued)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD) 10	Pipe Flow (MLD) 50	Direct Discharge (MLD)[b] Mean 10	Direct Discharge (MLD)[b] Mean 50	Direct Discharge (MLD)[b] Low[c] 10	Direct Discharge (MLD)[b] Low[c] 50	No. of POTWs	Indirect Discharge (MLD) Mean 10	Indirect Discharge (MLD) Mean 50	Indirect Discharge (MLD) Low[c] 10	Indirect Discharge (MLD) Low[c] 50
285	Paints, Varnishes	48	0.011	0.69	130	510	1.9	24	47	720	4100	11	230
286	Industrial Organic Chemicals	348	0.026	1.9	180	3000	2.9	220	87	140	2200	3.7	170
2861	Gum and Wood Chemicals	17	0.008	0.50	94	2200	1.3	65	5	260	260	0	0
2865	Cyclic Crudes, Intermediates, Dyes, Pigments	62	0.026	0.74	210	1400	0.19	85	39	240	14000	7.5	700
2869	Organic Chemicals Not Elsewhere Classified	268	0.026	2.3	210	4200	3.0	270	56	140	1300	3.7	85
287	Agricultural Chemicals	129	0.015	2.7	53	2800	1.8	270	19	260	930	0.11	230
2873, 2874, 2875	Fertilizers	95	0.019	3.8	100	1400	2.8	120	7	720	3700	230	590
2879	Pesticides	32	0.015	0.31	20	7000	1.3	700	12	23	620	0.023	9.8
289	Miscellaneous Chemical Products	175	0.011	0.45	160	1000	0.66	90	52	240	2500	11	180
2891	Adhesives and Sealants	46	0.019	0.22	310	1300	13	120	22	130	3000	5.9	190
2892	Explosives	20	0.004	0.19	140	670	0.030	41	2	770	770	43	43
2893	Printing Ink	17	0.000	0.12	220	710	4.3	90	13	280	3600	26	750
2895	Carbon Black	14	0.011	0.95	360	2400	3.2	260	1	16000	16000	2600	2600
2899	Miscellaneous Chemicals Not Elsewhere Classified	77	0.004	0.70	160	860	0.66	37	27	240	2200	11	45
291	Petroleum Refining	678	0.004	0.53	100	1000	0.19	120	28	96	3600	0.31	130
295	Paving and Roofing Material	121	0.004	0.19	160	1200	0.52	60	17	390	5200	14	1200
299	Miscellaneous Products of Petroleum and Coal	97	0.011	0.11	99	2700	0.019	220	11	720	9200	13	2300

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) (continued)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD)		Direct Discharge (MLD)[b]				No. of POTWs	Indirect Discharge (MLD)			
					Mean		Low[c]			Mean		Low[c]	
			10	50	10	50	10	50		10	50	10	50
3011, 3021, 3031, 3041, 3069	Rubber Processing	280	0.019	0.49	130	500	0.43	32	63	100	1900	4.3	130
3011	Tires and Inner Tubes	80	0.026	1.1	130	700	0.96	38	30	130	1700	4.3	120
3021	Rubber and Plastics Footwear	9	0.064	1.9	140	1400	5.0	100	2	52000	52000	2200	2200
3031	Reclaimed Rubber	8	0.019	0.11	23	2000	0.026	79	3	380	380	67	67
3041	Rubber and Plastics Hose and Belting	15	0.011	0.057	72	500	0.77	18	2	2800	2800	470	470
3069	Fabricated Rubber Products not Elsewhere Classified	168	0.019	0.34	160	380	0.39	28	33	95	950	0.37	84
3079	Miscellaneous Plastic Products	439	0.004	0.15	130	750	1.2	55	75	130	2200	2.1	120
311	Leather Tanning and Finishing	34	0.030	0.76	120	640	4.5	34	89	340	1300	4.4	69
32	Stone, Clay, Glass, and Concrete Products	970	0.004	0.19	120	1100	2.3	51	133	91	1500	0.31	100
3221, 3229, 3231	Glass and Glassware Products	47	0.011	0.66	210	780	4.4	56	37	210	2200	1.7	230
3241	Cement	121	0.015	0.68	78	2100	0.030	100	4	3700	3700	190	190
325	Structural Clay Products	108	0.004	0.13	91	660	0.076	40	9	75	420	0.31	5.6
326	Pottery and Related Products	56	0.011	0.38	150	830	5.9	56	14	91	300	2.2	62
327	Concrete, Gypsum, and Plaster	312	0	0.03	97	1100	2.2	26	19	230	2200	1.7	180
328	Cut Stone and Stone Products	92	0.004	0.19	140	1300	2.2	45	0	0	0	0	0

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) (continued)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD)		Direct Discharge (MLD)[b]				No. of POTWs	Indirect Discharge (MLD)			
					Mean		Low[c]			Mean		Low[c]	
			10	50	10	50	10	50		10	50	10	50
329	Abrasives, Asbestos, and Miscellaneous Nonmetallic Mineral Products	204	0.038	0.47	130	720	2.7	48	55	110	2200	0.21	180
33	Primary Metals Industries	1,197	0.019	0.68	170	1300	2.9	84	232	150	1400	1.7	110
331	Blast Furnaces, Steel Works, and Rolling and Finishing Mills	385	0.030	2.2	190	2100	4.9	180	94	110	2200	1.4	180
332	Iron and Steel Foundaries	191	0.023	0.42	170	800	1.0	54	67	230	3500	6.7	190
333, 334	Primary and Secondary Smelting and Refining of Nonferrous Metals	160	0.019	0.92	140	1300	3.8	100	30	130	2200	2.1	110
335	Rolling, Drawing, and Extruding of Nonferrous Metals	186	0.026	0.34	140	1100	1.2	84	68	280	1800	7.3	170
336	Nonferrous Foundaries	143	0.004	0.27	170	500	1.7	51	39	290	1400	6.4	120
34	Fabricated Metal Products, except Machinery and Transportation Equipment	1,173	0.011	0.14	120	900	1.7	67	398	96	1000	0.26	82
347	Coating, Engraving, and Allied Services	403	0.011	0.18	130	660	1.7	49	241	96	1000	0.042	66
3471	Electroplating, Plating, Polishing, Anodizing, and Coloring	316	0.015	0.15	130	610	1.4	42	221	100	1000	0.21	84
3479	Coating, Engraving, and Allied Services, Not Elsewhere Classified	86	0.011	0.087	160	720	3.8	75	43	85	1200	0.042	59
348	Ordnance and Accessories	46	0.011	0.34	140	2800	4.8	270	14	1300	3300	110	760

Table 7. Receiving Water Flow Rates for Industrial Discharge (Direct and Indirect) (continued)

SIC	Title	No. of Plants[a]	Pipe Flow (MLD)		Direct Discharge (MLD)[b]				No. of POTWs	Indirect Discharge (MLD)			
					Mean		Low[c]			Mean		Low[c]	
			10	50	10	50	10	50		10	50	10	50
3674, 3679	Electrical and Electronic Components Manufacture	111	0.004	0.20	120	430	0.91	29	85	96	620	0.034	14
4952	POTWs	NA	NA	NA	NA	NA	NA	NA	76	170	2900	0.030	160
4911, 4961	Electric Generation (Power Plants)	1,333	ND	ND	ND	ND	ND	ND	33	260	18000	0.034	1500
386	Photo Equipment and Supplies	27	0.008	0.66	160	1400	14	190	16	270	3600	9.8	1200
7221, 7333, 7395, 7819	Photographic Processing	—	0	0	0	0	0	0	33	130	4100	7.0	150

[a] Number of Plants = number of plants listed in IFD; for a more accurate accounting of the number of plants nationwide see the most recent census of Manufacturers conducted by the U.S. Bureau of the Census

[b] Depending on stream gage location the reported receiving water flow rate may or may not include the pipe flow; when stream flow is less than pipe flow the value may be corrected by adding the pipe flow to the receiving stream flow.

[c] Low flow = 7-day-10-year low flow (i.e., 7-Q-10)

NA = Not applicable.

ND = No data.

Source: IFD (1984).

stream flow for the industrial category. The 10th percentile indicates that 10 percent of the receiving stream flows for the industrial category of interest are less than the listed value; the 10th percentile represents the lower range of expected dilution. The flow data presented in Table 7 may be used to estimate a range in the concentration of a chemical substance discharged by one of the major industrial categories in a receiving water body for both mean and low flow conditions. For example, the range of in-stream concentrations of chemical A calculated using the daily plant loading (e.g., 10 kg/day) and generic data on the receiving stream flows for the organic chemicals industry (i.e., SIC 286) is presented below:

Industry/ discharge type	Stream flow percentile	Receiving stream flow (MLD)		Surface water conc. (ug/l)*	
		Mean	Low	Mean	Low
Organic chemicals (SIC 286)					
Direct discharge	10	180	2.9	56	3400
	50	3000	220	3.3	45
Indirect discharge	10	140	3.7	71	2700
	50	2200	170	4.5	59

*Calculated by dividing chemical release (i.e., 10 kg/day) by receiving stream flow (i.e., MLD).

Additional data presented in Table 7 that can be of occassional use are the pipe flow and number of plants in each industrial category. Pipe flow data can be used to calculate industrial wastewater concentrations. The data on number of plants can be useful in determining annual or daily loads per plant when waterborne emissions data are only available for an entire industrial category (NOTE: this calculation assumes all plants either produce or use the chemical of interest and that discharge is equally divided among all plants).

The concentration of a chemical substance in a receiving water body calculated by these procedures is a crude estimate. The estimated concentration essentially represents a worst-case situation. As can be seen from the two approaches discussed above, the results can vary by as much as several orders of magnitude. The models discussed in the subsequent section use data on the chemical/physical properties of the chemical substance of interest to evaluate the probable aquatic fate of the substance, along with dilution, to yield a much more accurate estimate of concentration.

4.2.2 Chemical Fate Models

The increased concern over toxic pollutant discharges to surface waters has lead to the recent development of numerous mathematical models. These models are designed to estimate the fate of a chemical upon discharge and its effect on the quality of the receiving water. The complexity of these models can range from relatively simple desk top calculations to complex computer algorithms. Table 8 lists several chemical fate models appropriate for freshwater aquatic systems. Depending on the sophistication of the model, mathematical models can account for transport processes such as advective and dispersive flows, multiple loading sources, multiple tributaries, and water column/bed sediment interactions. In addition, the transformation processes of volatilization, photolysis, hydrolysis, oxidation, and biodegradation can also be accounted for. The models listed in Table 8 are further discussed, along with technical guidance for modeling, in a waste load allocation document prepared by the EPA Office of Water Regulations and Standards; release of the document is expected during the summer of 1983.

It is not within the scope of this document to discuss all the models in Table 8; since the models essentially only differ in level of complexity, the selection of one model over another will depend on the level of detail desired and the resources available to the user. This section will discuss two of the models listed in Table 8, one that is straightforward and easy to use and another which is relatively complex. These two will probably be of most use to EPA-OTS, not solely because of their capabilities but also because of their accessibility and relative ease of use.

Generally, the simplest model that will sufficiently address the problem should be used. The time and cost of running sophisticated models will often prohibit their use; furthermore, the data requirements of complex models will often exceed the data that is available, thus making a more simplistic model--a less data intensive model--more desirable. The Water Quality Assessment Methodology, WQAM, (Mills et al. 1982) is the simplest model available. It is essentially a dilution type calculation described in the previous section; except that it does have provisions for degradation processes. The methodology is designed as a screening procedure that makes use of available generic data. WQAM's major advantage is that all the mathematical expressions are algebraic

Table 8. Chemical Fate Models for Estimating Pollutant Concentrations in Surface Waters

Model	Description	Comments	Reference
Water Quality Assessment Methodology (WQAM)	• steady-state, 1-dimensional model • requires only desk top calculations • provides canonical information • models, lakes, rivers, and estuaries	• easy to set up and use • no computer programming needed • recommended if time, costs, or information are restrictive	Mills et al. 1982 copies available from: ORD Publications USEPA, Cincinnati, OH 45268 513-684-7562
Simplified Lake/Stream Analysis (SLSA)	• steady-state, 1-dimensional model • solution either by desk top calculations or simple FORTRAN program • suitable for simplified lake and river systems	• easy to set up and use • computer programming not necessary; if used, only 280 bytes are required; suitable for microcomputers • well documented and suggested for use before using a more sophisticated model	HydroQual 1982 copies available from: William Gulledge 2581 M Street N.W. Washington, D.C. 20037 202-887-1183
Michigan River Model (MICHRIV)	• steady-state, 1-dimensional model • computer program written in FORTRAN • similar to SLSA but can model more than one reach • intended for metals • models rivers and streams	• easy to set up and use • requires minimal computer programming	Delos et al. 1983 other information available from: Bill Richardson USEPA Environmental Research Laboratory - Duluth Large Lakes Research Station

Table 8. Chemical Fate Models for Estimating Pollutant Concentrations in Surface Waters (continued)

Model	Description	Comments	Reference
Chemical Transport and Analysis Program (CTAP)	• steady state, 3-dimensional compartmental model • FORTRAN IV program suitable for numerous computers • it is similar to SLSA except more sophisticated; each CTAP compartment is equivalent to one SLSA "lake." • models streams, stratified rivers, lakes, estuaries, and coastal embayments	• requires extensive data input • requires computer programming; suitable for numerous computers; microcomputer version is available • one of the better documented models which may make it more desirable than other complex models	HydroQual 1982 copies available from: William Gulledge Chemical Manufactures Association 2581 M Street N.W. Washington, D.C. 20037 202-887-1183
Exposure Analysis Modeling System (EXAMS)	• steady state, 3-dimensional compartmental model • complex computer program • contains comprehensive second-order decay kinetics for organics, most models only have first-order kinetics • models organic chemicals • suitable for freshwater, non-tidal aquatic systems	• requires extensive data input • has been incorporated into EPA-OTS GEMS system thus making it more "user friendly" permitting non-computer trained personnel to use it. • well documented and recommended for use over most other models	Burns et al. 1982 assistance available from: Center for Water Quality Modeling Environmental Research Laboratory USEPA Athens, GA 30613 404-546-3585
Metals Exposure Analysis Modeling System (MEXAMS)	• steady state, 3-dimensional compartmental model • complex computer program • it is a combination of two models (MINTEQ and EXAMS) designed for modeling of metal loadings • suitable for freshwater, non-tidal aquatic systems	• complex metal dynamics requiring extensive data input • program is user oriented • provides some ancillary data • MEXAMS has not been field tested	Other information may be obtained from: Yasuo Onishi Battelle, Pacific Northwest Laboratories Richland, Washington 99352 509-376-8302

Table 8. Chemical Fate Models for Estimating Pollutant Concentrations in Surface Waters (continued)

Model	Description	Comments	Reference
Toxic Organic Substance Transport and Bioaccumulation Model (TOXIC)	• quasi-dynamic, 3-dimensional compartment model • program language is FORTRAN • complex biological uptake mechanisms • models pesticides in reserviors and aquatic impoundments	• applicable to IBM 370 and 750 Prime systems • only time-varying functions for loading, not flows • good for biological accumulation but lacking in chemical fate mechanisms • user support is limited; no user manual is available	Schnoor et al. 1981 other information may be obtained from: Jerry Schnoor Civil and Environmental Engineering Energy Engineering Division University of Iowa Iowa City, Iowa 52248 319-353-7262
Hydrological Simulation Program - FORTRAN (HSPF)	• time-varying, 1-dimensional model • complex FORTRAN program • designed for year round simulation • models organic pollutants • second-order decay mechanisms • models non-tidal rivers and streams and mixed lakes	• requires extensive data input • high computer costs because of direct access input/output requirements • HSPF has been applied for evaluations of best management practices (BMP)	Johanson et al. 1980 copies may be obtained from: Center for Water Quality Modeling Environmental Research Laboratory USEPA Athens, GA 30613 404-546-3585
Transient One-Dimensional Degradation and Migration Model (TODAM)	• time varying, 1-dimensional model • complex FORTRAN program, written in the preprocessor language FLECS • models organic pollutants • second-order decay mechanisms • models river and estuarine systems	• requires extensive data input and computer time • applicable to VAX or PDP 11/70 computers	Onishi et al. 1982 other information may be obtained from: Yasuo Onishi Battelle-Pacific Northwest Laboratories Richland, WA 99352 509-376-8302

Table 8. Chemical Fate Models for Estimating Pollutant Concentrations in Surface Waters (continued)

Model	Description	Comments	Reference
Channel Transport Model (CHNTRN)	• time-varying, 1-dimensional model • complex program written in basic FORTRAN • models for organic pollutants • second-order decay mechanisms • models rivers, lakes, estuaries, and coastal waters	• requires extensive data input • needs another model, CHNHYD, Channel Hydrodynamic Model, for computation of water flow • CHNTRN has not been field tested and documentation is currently under review	Yeh 1982 other information may be obtained from: Dr. G.T. Yeh Environmental Sciences Division Oak Ridge National Laboratory P.O. Box X Oak Ridge, TN 37830 615-574-7285
Finite Element Transport Model (FETRA)	• time-varying, 2-dimensional model • computer program written in FORTRAN IV • second-order decay mechanisms for organic pollutants • models rivers, estuaries, coastal systems, and completely mixed lakes	• input data requirements are extensive • FETRA can be used on IBM, VAX or CDC-7600 computers • FETRA has been field validated; however, documentation is still under review	Onishi 1981 other information may be obtained from: Yasuo Onishi Battelle-Pacific Northwest Laboratories Richland, WA 99352 509-376-8302
Sediment-Contaminant Transport (SERATRA)	• time-varying, 2-dimensional model • computer program written in FORTRAN preprocessor language FLECS • complex sediment transport mechanisms • second-order decay mechanisms for organic pollutants • models rivers and lakes	• requires extensive data input • applicable to VAX or PDP 11/70 computers • SERATRA has been field tested and is available for use • technical assistance can be obtained from: EPA Athens Env. Research Lab. Center for Water Quality Modeling Athens, GA 30613 404-546-3546	Onishi and Wise 1982a Onishi and Wise 1982b copies available from: ORD Publications Center for Environmental Research Information USEPA Cincinnati, OH 45268 513-684-7562

Table 8. Chemical Fate Models for Estimating Pollutant Concentrations in Surface Waters (continued)

Model	Description	Comments	Reference
Estuary and Stream Quality Model (WASTOX)	• time-varying, 3-dimensional model • program language is FORTRAN • sophisticated second-order organic decay kinetics • models rivers, lakes, and estuaries	• very data intensive model • user must provide hydrodynamic flows between model compartments • applicable to IBM 370 or PDP 11/70 systems • WASTOX is still in development stage; release is not known; will probably be the most sophisticated model available when finished	Other information may be obtained from: Dr. John Connolly Environmental Engineering and Science Manhatten College Bronx, NY 10471 212-920-0276
Chemical and Stream Quality Model (TOXIWASP)	• time-varying, 3-dimensional model • program language is FORTRAN IV • comprehensive second-order decay kinetics for organic pollutants • models rivers and estuaries and it can be applied to lakes	• data intensive model • applicable to a PDP 11/70 system • an aquatic food chain routine is to be incorporated • TOXIWASP has not been validated or formally released yet by the EPA	Currently being developed at: Center for Water Quality Modeling Environmental Research Laboratory USEPA Athens, BA 30613 404-546-3546

Notes: The models are generally listed in order of increasing complexity. The state, dimensionality, and decay mechanisms are indicators of the model's sophistication. A time-varying, 3-dimensional model, with second-order decay kinetics, will be the more complex model type. Time-varying means the loading rates and hydrological flows do not have to be held constant as in steady state models. All the models have capabilities for accounting for water column/bed sediment interactions. Estimates of up to two man-months are made for data set-up and model preparation for the more complex models.

and can be solved using a desk calculator; the analyst needs no programming experience. The calculations need relatively little external input since much of the needed information is provided by tables and figures within the manual. The user need only provide minimal hydrological and climatological data peculiar to the system being modeled. WQAM predicts far field, average steady state pollutant concentrations in lakes, rivers, and estuaries as a function of long-term average minimum and maximum non-point source loads.

WQAM is a two-volume document divided into six chapters. The first three chapters provide general information for the user. This includes introductions into transport and transformation processes and canonical data. Included in the data are physico-chemical and usage characteristics for the EPA's 129 Priority Pollutant List. The remaining three chapters provide a step-by-step approach for assessing the fate and effects of a pollutant in lakes, rivers and streams, and estuaries.

The call numbers for WQAM are EPA-600/6-82-004a and b; copies are available from the EPA's Environmental Research Lab in Athens, Georgia, or the EPA Office of Publications in Cincinnati.

The most useful model to EPA-OTS for estimating surface water concentrations, because of its detail and availability, is the Exposure Assessment Modeling System (EXAMS) (Burns et al. 1982). EXAMS is contained within the EPA-OTS Graphical Exposure Modeling System (GEMS) (GSC 1982a). GEMS is a computer system that integrates environmental modeling, physico-chemical properties estimation, and environmental data sets with a data manipulation feature that includes statistical analysis and graphic display capabilities. Its purpose is to aid environmental analysts in the efficient performance of exposure assessments.

EXAMS was developed by the EPA's Environmental Research Laboratory in Athens, Georgia. The model is designed to allow for the rapid screening and evaluation of organic chemicals in streams, rivers, ponds, and lakes due to continuous long term toxicant loadings. EXAMS is a steady state, 3-dimensional model which integrates the physico-chemical properties of the pollutant with the transport and physico-chemical characteristics of the aquatic system. Steady state means that the loading and transport mechanisms are assumed to be constant. As a 3-dimensional model, EXAMS divides the aquatic system into water compartments and associated sediment and biotic compartments; each compartment is assumed to be homogeneous. Concentrations are estimated for each compartment, and the compartments are linked via differential equations.

EXAMS, like all mathematical models, requires an extensive amount of input data. Table 9 lists the input requirements for EXAMS; it also exemplifies the complexity of the model. The requirements can be divided into three groups: environmental data, chemical data, and loading data. The environmental data include climatic, biological, hydrological, and sediment characteristics. The chemical data input relates the various chemical characteristics (e.g., partition coefficients) of the compound of interest. Loading data input concerns the influx rate of the compound plus stream flow, rainfall, interflow, non-point source flow, and drift (Fiksel et al. 1981). EXAMS does contain six canonical environment set-ups which can be used for nonsite-specific screening procedures.

Another advantage to using EXAMS is that it incorporates comprehensive second-order kinetics for organic chemical decay. Most models assume only first-order decay kinetics. EXAMS, however, is not appropriate for inorganic constituents such as heavy metals. MEXAMS (see Table 8) is very similar to EXAMS and is designed specifically for metals transport.

Copies of EXAMS and user guidance may be obtained from:

The Center for Water Quality Modeling
Environmental Research Laboratory
USEPA
College Station Road
Athens, Georgia 30613
404-546-3123

It is suggested that the models in Table 8 be reviewed to see which one can provide the best representation of a particular scenario. Again, however, the logistics of running those models as compared to WQAM or EXAMS may discourage their use. Another source of models which may be useful for surface water quality is the Environmental Modeling Catalogue (USEPA 1980a).

4.3 Estimation of Concentration in Ground Water

The major sources of ground water contamination investigated by EPA-OTS are releases from waste disposal sites and leaking above and underground storage tanks (Note: Agricultural chemicals can also be a major source of ground water contamination.). Volume 3 of this methods series (i.e., Disposal Volume), discusses in detail waste disposal practices and associated releases. Leachates from disposal sites will percolate through the unsaturated zone to the saturated zone.

Table 9. EXAMS Input Requirements

Parameter	Units
River and tributary flow	m^3/hr
Non-point source water input (direct surface runoff)	m^3/hr
Compartment length	m
Compartment width	m
Compartment surface area	m^2
Compartment depth	m
Compartment volume	m^3
Stream velocity	m/s
Chlorophyll concentration	mg/L
pH	—
pOH	—
Concentration of suspended sediment	mg/L
Percent organic carbon content of benthic and suspended sediment	—
Extinction coefficient	m^{-1}
Non-point source sediment input	kg/hr
Length for dispersive mixing	m
Eddy dispersivity	m^3/hr
Cross sectional area of adjoining reaches	m^2
Interflow	m^3/hr
Reaeration rate coefficient	cm/hr
Wind speed over river	m/s
Rainfall	mm/month
Cloud cover	tenths

Table 9. EXAMS Input Requirements (Continued)

Parameter	Units
Evaporation loss	mm/month
Water temperature	°C
Sediment load	kg/hr
Latitude	degrees
Spectral irradiance	protons/cm^2/s/nanometers
Distribution function (ratio of optical path length to vertical depth in water)	—
Sediment density	g/cm^3
Percentage water weight of sediment	--
Cation exchange capacity of sediment	milli eg/100 g dry wt
Anion exchange capacity of sediment	milli eg/100 g dry wt
Molar concentration of oxidants	moles/L
Biomass in water and sediment	mg/L and g dry wt/m^2
Fraction of planktonic biomass	—
Biotemperature	°C
Bacterial density	cells/100 g dry wt
Percent of active bacteria	—
Dissolved organic carbon	mg/L

Source: Fiksel et al. 1981.

Transport of the contaminants is dependant on many meteorological, chemical, hydrological, and geological parameters, as well as the nature of the pollutant. Unlike estimating concentrations in surface waters, estimates of releases to ground water should only be made with the aid of mathematical models. There are too many variables determining quantity and speed of leachate transport through the unsaturated zone to reasonably simplify for making conservative estimates. The numerous assumptions required to make such estimates would only lead to meaningless information.

The following parts of this section will discuss the nature and requirements of ground water models and those models which will be of prime use to EPA-OTS exposure analyses. Models designed to predict the dynamics of leachate movement can be divided into two major groups: (1) release rate models--those that estimate the quantity and rate of leaching from a disposal site--and (2) solute transport models--those that predict the migration of the leachate from the source. The use of these models does require some knowledge in hydrogeology, and the user is advised to consult references such as Mercer and Faust (1981) and Freeze and Cherry (1979).

4.3.1 Release Rate Models

Release rate models are designed specifically for predicting the amount of leachate from a waste disposal site that is released into the subsurface or unsaturated zone. This information is required for predicting the amount of contaminant that reaches ground water using a solute transport model.

Release rate models are generally divided into three components: leachate generation, constituent concentrations, and leachate release rates from the site (Versar 1983). The primary factors affecting these components are listed in Table 10. Data requirements for these models usually include precipitation characteristics (e.g., amount, duration, frequency), water table elevation, evapotranspiration, solar radiation, temperature, humidity, soil profile, hydraulic conductivity, and pressure head (Versar 1983). Measurements and characteristics of the landfill are also required.

Table 11 lists several release rate models and their advantages and disadvantages. Because of time and cost restraints of the more complex models, the more simplified and less data intensive versions made be the most useful. Of the four models listed, the Release Rate Computations (RRC) (SCS Engineers 1982 as cited in Versar 1983) and the Post-Closure Liability Trust Fund Model (PCLTF) (USEPA 1982b as cited in Versar 1983)

Table 10. Primary Factors Affecting the Three Components of Leachate Release Rate Models

Leachate generation	Leachate constituent concentrations	Leachate release
Precipitation	Waste composition	Landfill design
Liquid content of waste	Physico-chemical properties	Liner type
Ground water intrusion	Contact time	
Soil moisture capacity	Chemical reactions	
Evapotranspiration	Facility age	
Runon/runoff control		
Landfill type		
Surface/cap conditions		

Source: Versar 1983.

Table 11. Leachate Release Rate Models

Model	Advantage	Disadvantage	Reference
Release Rate Computations	• simple, easy to use calculations	• limited in scope because of numerous assumptions	SCS Engineers 1982
Hydrologic Evaluation of Landfill Performance (HELP/HSSWDS)	• requires only minimal amounts of data; • estimates both vertical and lateral dispersion	• ignores pertinent rainfall characteristics • leachate dispersion capabilities have not been field tested	Perrier and Gibson 1980
Post-Closure Liability Trust Fund (PCLTF)	• addresses all components of leachate release; • suitable for many situations; provides some generic site types	• complex and data intensive	USEPA 1982b
DRAINMOD/DRAINFIL	• can account for passage of leachate in both unsaturated and saturated zones	• complex and data intensive; high cost of running model	Skaggs 1982

Source: Versar 1983.

are probably the most useful. The ease of use and low cost of RRC will make it desirable when time and money are limited. PCLTF is the only one of the models listed that accounts for all three components and as such has a higher degree of accuracy.

4.3.2 Solute Transport Models

Whereas release rate models estimate the quantity and quality of constituents that may leach from a disposal site, solute transport models predict the dispersion of the constituents from the source. Solute transport models are mathematical models which, depending on the complexity of the model, can estimate the migration of a chemical over time in one, two, or three dimensions (Versar 1983).

Mathematical models employ sets of equations, based on explicit assumptions, to describe the physical processes affecting ground water flow, which may in turn be used to predict contamination. There are two sets of mathematical models, stochastic and deterministic. Stochastic models attempt to define cause and effect relationships using probablistic methods; deterministic models define the relationships based on the physical processes involved (USEPA 1982a). Deterministic models are the more applicable models; there are two types, analytical and numerical.

Analytical models simplify mathematical equations by making generalized assumptions, thus allowing solutions to be obtained by analytical methods. They provide estimates of waste constituent concentrations and distributions by simulating plume migration from the source. The generalized assumptions usually involve steady state conditions, radial flow from the source, and an infinite aquifer extent (Mercer & Faust 1981). Analytical models are not as complex as numerical models and as such are less time consuming and expensive to run (USEPA 1982a).

Numerical models characterize ground water contamination without simplifying the physical and chemical parameters. Equations are approximated numerically resulting in a matrix equation that requires a computer for solution. Numerical models are more sophisticated than analytical models and will require more data, time, and money to run (USEPA 1982a).

Both types of models address physico-chemical and hydrogeological parameters. Table 12 lists advantages and disadvantages of both analytical and numerical models. Table 13 outlines some of the variables that are addressed by solute transport models.

Table 12. Comparison of Analytical and Numerical Models

Model type	Advantages	Disadvantages
Analytical Models	• Provide quantitative-predictive assessments • Attempt to specify pollutant concentrations • Allow quick assessments at moderate cost • Identify physical processes	• Physical processes incorporated are not fully understood • Require specialized skills and equipment • Require field verification • May have limited applicability based on model theory
Numerical Models	• Provide quantitative-predictive assessments • Identify physical processes • Attempt to specify pollutant concentrations • Applicable to wide range of complex situations • Can be applied as a research tool	• Physical processes are not fully understood • Require analytical and field verification • Are data intensive • Potentially high operating costs • Require specialized skills • May have limited applicability based on model theory

Source: USEPA 1982a.

Table 13. Physical Parameter Characteristics Addressed by Ground Water Models

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Hydrologic Zone

- Saturated - Void spaces in material filled with water; below water table.
- Unsaturated - Void spaces in material at least partially filled with air; above water table.

Hydrologic Characteristics (saturated-unsaturated zones)

- Porosity
  - Intrinsic: Movement of liquids/gases through porous media.
  - Secondary: Movement of liquids/gases through fractures, joints, or solution cavities in the media.
- Homogeneity
  - Homogeneous: Material having identical characteristics at all locations, uniform.
  - Heterogeneous: Material having different characteristics at different locations, non-uniform.
- Isotrophy
  - Isotropic: Hydraulic properties of material are equal in all directions.
  - Anisotropic: One or more of the hydraulic properties of the material vary according to flow direction.

Transport Mechanisms

- Homogeneity
  - Miscible: Uniform mixing of contaminant in system.
  - Immiscible: Non-uniform mixing of contaminants.

Table 13. Physical Parameter Characteristics Addressed by Ground Water Models (continued)

- Dilution
  - Convection: Transport of contaminants by convective ground water flow only.
  - Multiple: Transport of contaminants by convection, dispersion, and conduction.
- Phases
  - Single: Single phase (e.g., liquid phase).
  - Multiple: More than one phase (e.g., liquid-gas phases).

Contaminant Properties

- Constituent Number
  - Single: Model transport of single constituent.
  - Multiple: Model transport of two or more constituents.
- Contaminant Type
  - Organics: Organic chemicals/compounds.
  - Inorganics: Inorganic chemicals/compounds (non-metals).
  - Metals: Metal species.
  - Radioactives: Radioactive materials.
- Degradation
  - Conservative: Movement of contaminants without degradation.
  - Nonconservative: Movement of contaminants considering degradation which could include sorption, chemical, or biological degradation.

Source: USEPA 1982a.

The transport to and fate of contaminants in ground water are affected by subsurface factors which can be categorized into two major groups, those of the unsaturated zone (soil column) and those of the saturated zone (ground water aquifer). Because of the dissimilarities between the two, most ground water models will only consider one or the other.

Many investigators have designed their own ground water models to suit the need for their particular study; therefore, there are numerous models available to an investigator (USGS 1976b). The remainder of this section will discuss examples of ground water models which will probably be of most use to EPA-OTS.

(1) Analytical Models. Again, because they are not as complex as numerical models, analytical models will probably be most useful. The two models described here are probably sophisticated enough to provide a sufficient level of accuracy for most investigations.

(a) SESOIL. The Seasonal Soil Compartment Model (SESOIL) was developed by Bonazountas and Wagner (1981) for the Office of Pesticides and Toxic Substances. SESOIL is described as a "user-friendly" statistical-analytical model designed for long-term environmental pollutant fate analysis for the unsaturated zone. It can describe water and sediment transport in terms of quality and quantity plus pollutant transport and transformation. It can be used for a wide variety of applications including screening and review of new chemicals.

Model simulations are based on a three cycle rationale: the water cycle, sediment cycle, and the pollutant cycle. The water cycle takes into account rainfall, infiltration, exfiltration, surface runoff, evapotranspiration, ground water runoff, snow melt, and interception (USEPA 1982a). The sediment cycle includes (1) sediment resuspension due to wind and (2) sediment washload due to rain storms. The pollutant cycle characterizes convection, diffusion, volatilization, adsorption/desorption, chemical degradation, complexation of metals, biological action, hydrolysis, oxidation, and nutrient cycles (USEPA 1982a). The user has the option of running the model on one of four different levels of spatial and time variations.

Aside from predicting chemical distribution in the unsaturated zone, other outputs include hydrologic relationships among precipitation, surface runoff, infiltration, evapotranspiration, soil moisture, and ground water runoff. Concentrations are reported according to the level of application.

The real advantage in using SESOIL for modeling of the unsaturated zone is that it has been integrated into GEMS (see Section 4.2.2). This greatly enhances the application of the model. In addition, input and output data files have been developed to further support the operation of SESOIL. SESOIL, therefore, provides a detailed mechanism, with a high degree of accuracy, to model contaminants in the unsaturated zone with minimal effort. The results may then be used as input into a model designed for the saturated zone.

(b) AT123D. The Analytical Transient One-, Two-, and Three-Dimensional Simulation Model (AT123D) (Yeh 1981) was developed at the Environmental Sciences Division of the Oak Ridge National Laboratory. AT123D provides generalized analytical transient one-, two-, or three-dimensional solutions for estimating contaminant transport in both the unsaturated and saturated zones. The model contains 450 options: 288 for the three-dimensional case, 72 for each of the two dimensional cases (x-z plane and x-y plane), and 18 for the one-dimensional case in the longitudinal direction. The model provides eight different sets of source configurations, three kinds of source releases, four variations of aquifer dimensions and modeling of radioactive wastes, chemicals, and heat. Transport mechanisms characterized are: advection, hydrodynamic dispersion, adsorption, degradation, and waste losses to the atmosphere from the unsaturated zone.

AT123D is written in FORTRAN and model setup time can be extensive. Although the model has yet to be field validated, it has been applied in a number of investigations. AT123D is contained within the EPA-OTS's computer modeling library; however, it has not been integrated into the GEMS system.

(2) Numerical Models. Numerical models provide the best approach to modeling hydrogeologic conditions and contaminant characteristics. However, they are often more difficult to use because they require complex data and involve greater costs to run. Their immediate use in exposure assessments is minimal because of the sophistication needed to run them, but they will be of greater use in the future. The following are descriptions of two numerical models.

(a) RWSTM. The Random Walk Standard Transport Model (RWSTM) (Prickett et al. 1981) is a generalized computer code that can simulate a large class of solute transport problems in ground water. The model characterizes both dispersion and attenuation of conservative and non-conservative contaminants in the saturated zone. The model can simulate one- or two-dimensional nonsteady/steady flow problems, time-varying pumpage, injection by wells, recharging, exchange between surface and ground waters, and flow from springs. Contaminant concentrations can be identified in any segment of the model.

Although the user manual provides the necessary information for model application, the user is still required to have hydrogeological, mathematical, and programming knowledge. RWSTM has been field validated and is available for use. Copies of RWSTM are available from the Illinios State Water Survey Division, Illinois Department of Energy and Natural Resources, Champaign, Illinois, 61820.

(b) FEMWASTE. FEMWASTE (Yeh and Ward 1981, as cited in Versar 1983) was developed by G.T. Yeh of the Oak Ridge National Laboratory. It is a two-dimensional mass transport model for both the unsaturated and saturated zones. FEMWASTE combined with FEMWATER (Yeh and Ward 1981b, as cited in Versar 1983), a ground water flow model, can provide solute transport estimates for a variety of boundary and initial moisture conditions (Versar 1983). The model accounts for the effects of convection, dispersion, sorption, and first-order decay.

FEMWASTE is a complex model, and it too will require the user to have knowledge of hydrogeology, differential equations, and programming. FEMWASTE has been field validated and is presently being used by the USGS in Carson City.

4.3.3 Practical Model Application

A practical application of two of the ground water models previously discussed is illustrated in a recently completed exposure assessment involving the modeling of nitrilotriacetic acid (NTA) in ground water. GSC (1982b), using information from Versar (1982), predicted the fate of NTA in ground water. They used two models, SESOIL and AT123D. SESOIL was used to estimate the transport of NTA in the unsaturated zone, and AT123D was used for the saturated zone. The results from SESOIL were used as the inputs for the AT123D model. These two models were chosen because of their versatile capabilities and their relative ease of use. In order to run the model, GSC had to make several estimates and assumptions. The information used for the modeling is as follows:

Unsaturated Zone

- Table 14 lists the information used in SESOIL for modeling the unsaturated zone.

- The source of NTA was residential septic tanks. A representative housing density of 2,000 houses per 1,000 acres was used to

Table 14. Parameter Values Used in SESOIL to Estimate NTA Concentrations in the Unsaturated Zone

---

Time of simulation: Monthly simulation for 10 years*

Effluent quantity per house: 300 gal/day (4 persons per house)

Average precipitation: 8.5 cm/month**

Soil density: 1.32 gm/cm^3

Disconnectedness Index: 4.0

Porosity: 0.35

Permeability: 7.15 x 10^{-9} cm^2 (soil type 1)
1.44 x 10^{-8} cm^2 (soil type 2)
5.32 x 10^{-8} cm^2 (soil type 3)

NTA solubility: 1,200 mg/l

Adsorption coefficient: 6.3 [(ug/gm)/(ug/ml)]

Henry's Law constant: 0.0***

Molecular weight: 191-257 gm/mole

Decay rate: Upper layer 0.11 day^{-1} (half-life = 6.3 days)
0.16 day^{-1} (half-life = 4.3 days)
0.22 day^{-1} (half-life = 4.3 days)
Lower layer 0 day^{-1} (half-life = ∞)
0.00019 day^{-1} (half-life = 10 yr.)
0.00038 day^{-1} (half-life = 5 yr.)
0.0019 day^{-1} (half-life = 1 yr.)

Source: GSC 1982b.

* Maximum permissible simulation period in SESOIL.

** Observed at Clinton, Massachusetts, a relatively wet location.

***Assumed 0.0 because of NTA's high solubility and relatively low vapor pressure.

estimate the total NTA effluent to ground water. However, to facilitate SESOIL output, only a single house was used, and the result was extrapolated for the total.

- The average septic drainage area of each house was estimated to be 50 m^2.
- The mean concentration of NTA in the effluent was estimated to be 12 mg/l (6.1 mg/l - 18 mg/l).
- The unsaturated soil column was estimated to be 5 meters, of which the top meter was assumed to be aerobic and the lower four meters less aerated.
- Three different soil types were used, each assigned different hydraulic conductivities.
- Three different decay rates of NTA were used for the top meter.
- Four different decay rates of NTA were used for the lower four meters.
- Thus, 36 runs in all were made for NTA transport using SESOIL (3 soil types x 3 decay rates - upper layer x 4 decay rates - lower layer).

Saturated Zone

- Table 15 lists the information used in AT123D to model NTA transport in the saturated zone.
- The results from SESOIL were used as the source of NTA (kg/hr) to the saturated zone.
- The saturated zone was estimated to be a water table aquifer with a mean depth of 50 m.
- The model calculates the concentrations of NTA at different levels of the aquifer.
- AT123D was run 36 times to correspond to the runs of the SESOIL model.

Table 16 presents the range of NTA concentrations from a 50 m well. The aquifer is located immediately below the hypothetical 2,000-house

Table 15. Parameter Values Used in AT123D to Estimate NTA Concentrations in the Saturated Zone

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Time of simulation: 136 years*

Hydraulic gradient: 0.05**

Distribution coefficient: 0.0031 m^3/kg [3.15 (ug/gm)/(ug/ml)]***

Porosity: 0.35

Bulk density: 1320 kg/m^3 (1.32 gm/cm^3)

Dispersivity: 30 m (longitudinal)
5 m (lateral)
5 m (vertical)

Decay rate: 0 hr^{-1} (half-life = ∞)
7.92×10^{-6} hr^{-1} (half-life = 10 yr.)
1.58×10^{-5} hr^{-1} (half-life = 5 yr.)
7.92×10^{-5} hr^{-1} (half-life = 1 yr.)

Source: GSC 1982b.

* An average detention time calculated on the basis of assumed drainfield area, hydraulic conductivity, and hydraulic gradient.

** A slightly higher than average value was conservatively assumed.

***Taken as half of the value used in SESOIL.

Table 16. Simulated Average NTA Concentrations in Ground Water at 20 m Depth[1] in an Aquifer of 50 m Average Depth

Soil type[2]	NTA half-life in aquifer (years)	NTA concentration in aquifer[3] (ug/l)	
		Septic effluent 6.1 mg/l NTA	Septic effluent 18 mg/l NTA
Soil type 1	1	0.08-0.14	0.23-0.41
Soil type 2	1	0.25-0.44	0.74-1.3
Soil type 3	1	1.0-1.5	3.0 -4.5
Soil type 1	10	6.5-12	20-36
Soil type 2	10	8.5-15	26-45
Soil type 3	10	11-19	33-57

Source: GSC 1982b

[1] Depth at which average concentration occurs in a well with a screened, penetrating depth of 50 meters into an aquifer of 50 meters average depth.

[2] Soil type 1 = Moderate percolation; loam and silt soil.
Soil type 2 = Between soil types 1 and 3 (i.e., sandy loam to loamy sand)
Soil type 3 = Rapid percolation; sandy soil.

[3] Concentration ranges for the three biodegration half-lives in the aerobic zone of the soil column are presented for the low and high end of the expected septic system effluent concentrations.

complex, and thus, the concentrations can be considered conservative. The concentrations of NTA were estimated to range from 0.08 ug/l (assuming: low end of expected septic system effluent concentration = 6.1 mg/l; the shortest half-life in the aerobic zone = 3.1 day; soil with moderate permeability = soil type 1; and the shortest half-life in the saturated zone = 1 year), to 57 ug/l (assuming: high end of expected septic system effluent concentration = 18 mg/l; the longest half-life in the aerobic zone = 6.3 day; soil with higher permeability = soil type 3; and the longest half-life in the saturated zone = 10 years). The NTA concentrations are those at the 20 m depth; these are the average over the 50 m depth. Because NTA concentrations will decrease with increased depth, wells that only collect water near the upper layers of the aquifer will contain higher concentrations of NTA; water in wells that penetrate to the bottom of the aquifer will contain lower concentrations (Versar 1982).

5. CONCENTRATION OF CHEMICAL SUBSTANCES IN FINISHED WATER

Section 4 discusses the parameters affecting the concentrations of chemical substances in surface and ground waters and presents techniques for estimating chemical concentrations. Treatment applied to those waters prior to their use by consumers will affect the chemical concentration and, in turn, determine the consequent exposure via drinking water. The effects of treatment are discussed in this section.

Drinking water may be drawn from either public or private supplies, and may be treated or used directly. Public supplies that are treated are subject to a myriad of unit processes, discussed in Section 5.1.1. Section 5.1.2 guides the reader in methods to (1) determine or predict the processes used by water supply systems and (2) quantify the effect of water treatment on the chemical substance of interest. Section 5.2 discusses the methods used by consumers to treat water in their homes.

5.1 Public Water Systems

Section 2 of this report briefly discussed the two types of water treatment systems commonly used by municipalities. Type I (filtration) plants employ sedimentation, coagulation, flocculation, and filtration; the finishing step usually involves adding chlorine and fluoride. Type II (softening) plants use lime and soda ash to precipitate the cations that cause water hardness (calcium and magnesium), then utilize settling, filtration, and finishing (see Figure 3). The following subsections discuss the unit processes that comprise these treatment schemes. A number of other processes may be used for removal of specific contaminants; these processes are generally incorporated into the basic Type I and II schemes and are also discussed below.

5.1.1 Unit Processes in Water Treatment

The typical systems discussed in Section 2 are simply combinations of unit processes. The following subsections define the unit processes used in water treatment, discuss the purpose(s) for which they are intended, and describe the conditions under which and combinations in which they are used.

Some of the unit processes described below are rarely used; others are nearly universal. Table 17 presents information on the frequency of their use. Each subsection discusses the combinations (or treatment schemes) in which a unit process is customarily used.

Table 17. Frequency of Use in U.S. of Water Treament Methods

Treatment Method	Surface Water Utilities		Ground Water Utilities		Comments**
	Number of Systems*	Percent+	Number of Systems*	Percent++	
Aeration	1,552	9.4	4,236	2.2	May include some iron removal and taste and odor control applications.
Prechlorination	3,200	19	4,592	2.4	
Coagulation	4,329	26	2,056	1.1	
Sedimentation	4,343	26	2,504	1.3	
Corrosion control	2,333	14	3,270	1.7	pH adjustment.
Taste and odor control	2,542	15	2,413	1.3	May overlap with aeration, prechlorination; may include activated carbon usage.
Iron removal	1,453	8.8	5,163	2.7	May overlap with aeration, coagulation.
Softening	1,680	10	7,197	4.1	May include ion exchange as well as lime-soda softening.
Filtration	5,421	33	5,896	3.1	May include activated carbon filtration as well as sand filtration.
Ammoniation	1,346	8.2	2,457	1.3	
Disinfection	8,569	52	32,200	17	May include chlorination and ozonation.
Fluoridation	3,068	19	5,999	3.1	Fluoride adjustment; may include fluorine removal.
Other	1,485	9.0	4,070	2.1	Electrodialysis, reverse osmosis, etc.
Aeration + coagulation + Sedimentation + Filtration	1,317	8.0	1,574	0.8	

Source: FRDS Data Retrieval, FY1984.

*Includes both community and non-community systems.

+Total number of active surface water systems is 16,437; this includes systems that only obtain water from other surface water utilities.

++Total number of active ground water systems is 190,797; this includes systems that only obtain water from other ground water utilities (FRDS contains many ground water systems that serve less than 100 people).

**See Section 5.1.1 for explanation of comments.

Available data on removal of chemical substances during the most common processes used in water treatment are presented in Table 18. Removal data available for processes seldom used are not included. These uncommon processes, used only at a few plants worldwide, include: ion exchange, reverse osmosis, electrodialysis, and ultrafiltration. Data may be reported for specific compounds or for chemical classes. Table 18 also lists some data on removal of Total Organic Carbon (TOC). The organic constituents with which EPA is generally concerned occur at the low ppb or ug/l range, and constitute only a small fraction of the TOC. Data on TOC removal is presented for two reasons:

- The level of TOC in water is known to affect the degree of formation of chlorinated compounds and the degree of reaction between trace chemicals and chlorine (Morris and Baum 1978).
- Removal of TOC by a water treatment process may be used, in the absence of other data, as a qualitative indicator of whether or not a chemical of interest that comprises a small fraction of the TOC is affected by treatment.

Data on TOC removal should not be applied indiscriminantly to determine removal efficiency for all organic compounds.

The data in Table 18 may come from bench-scale studies performed in the laboratory, from pilot-scale studies conducted to aid in treatment plant design, or from tests of the raw and treated water in actual treatment plants. The data from all three types of studies should be valid for assessing removal efficiency. The removal processes in drinking water treatment plants are physical and chemical processes, which can be carefully controlled in small-scale studies (rather than biological processes, which are more difficult to control in the laboratory). The key to interpreting the data in Table 18 is to determine the basic appropriateness of study design by evaluating consideration such as:

- Are raw water concentrations treated in the study representative of those encountered in water treatment?
- Is the pH at which the study was conducted near the pH of the water at that point in treatment?
- Are doses of treatment chemicals used in the study reasonable?

The pH of water during drinking water treatment can fluctuate widely. Many removal processes (notably adsorption, oxidation, and

Table 18. Removal of Contaminants During Drinking Water Treatment

Process	Contaminants	Removal efficiency	Comments	Reference
Aeration	Trichloroethylene	70 - 90%	Pilot scale, laboratory, and field aeration tests. 4 cm diameter glass column, 1.2 m long with fitted glass diffuser in bottom. TCE added to tap water, concentration 100 to 1,000 ug/l. Temperature varied. Air-to-water ration 4:1, contact time of 10 minutes.	Love et al. (1983).
	Tetrachloroethylene	88 - 91%	Pilot scale tests at Glen Cove, N.Y. using diffused air and packed tower aeration units. Air-to-water ratio 15:1. Influent levels of 49 ug/l. Column conditions (i.e., flooded or unflooded) and packing materials were varied.	Ruggiero et al. (1982).
	cis-1,2-dichloro-ethylene	58 - 85%	Pilot scale tests, diffused air aeration. Glass column with 36 cm diameter and 3 m deep, 5 diffusers, 10 minute contact time. Air-to-water ratio from 5:1 to 30:1.	Ruggiero et al. (1982).
	1,1-Dichloroethylene	97%	Pilot scale tests on diffused air aeration. Test specifications included a glass column with 76 cm diameter, 3 m deep, contact time of 10 minutes and air-to-water ration of 4:1.	Ruggiero et al. (1982).
Chemial oxidation; hydrolysis; precipitation; ozonation	Antimony	to < 2 mg/l	Hydrogen sulfide precipitation. Antimony sulfide is soluble to < 2 mg/l. Removal of amounts in excess of stoichiometric concentrations of H_2S should be accomplished.	Stone et al. (1975).
	Trihalomethanes	76%	Using $KMnO_4$ (0.4 mg/l) as a disinfectant instead of chlorine dioxide resulted in a net reduction of trihalomethane production of 76% during full scale testing.	Blanck (1979).
	Parathion	75%	Pilot study using $KMnO_4$, further details were not reported.	Stone et al. (1975).
	Heptachlor	88%	Oxidation process; further details were not reported.	Stone et al. (1975).
	Dieldrin	~100%	Oxidation process; further details were not reported.	Stone et al. (1975).

Table 18. (Continued)

Process	Contaminants	Removal efficiency	Comments	Reference
Chemical oxidation (continued)	Aldrin	~100%	Oxidation process; further details were not reported.	Stone et al. (1975).
	Lindane	75%	Oxidation proces; further details were not reported.	Stone et al. 91975).
	Color	32 - 49%	Oxidation process; further details were not reported.	Cheremisinoff et al. (1976).
Direct filtration	Color	80-85%	Bench scale tests. The tests were performed using pilot filter 2.54 cm ID, 3.5 mg/l of a chlorine-resistant cationic polymer as coagulant, and a flow of 1.3 mm/s.	Scheuch and Edzwald (1981).
	Asbestos	99%	Direct filtration of Lake Superior waters using mixed media filters in conjunction with coagulation, flocculation, and chemical addition.	Peterson et al. (1980).
Coagulation	Fulvic acid	90 - 92%	The tests were bench scale jar tests, using alum and $FeSO_4$ as coagulants. Minor pH adjustments were made when necessary.	Randtke and Jepsen (1981).
	Humic acid	91 - 96%		
	THM precursors	57 - 99%		
	TOC	36-53%	Removal of TOC using alum coagulation is most effective at a pH of 5 and increases with increasing alum dosage, which may exceed that necessary for turbidity removal. An alum dose of 100 mg/l at pH 5 removed 53% TOC in bench scale tests using reconstituted Mississippi River water.	Semmens and Field (1981).
	Cobalt	62%	Lab scale coagulation test using the polymer chitosan (100 - 200 mg/l) was shown to be effective for a variety of metals with modest contact times (20 minutes). Cobalt was reduced 62% in 50 mg/l Co test solutions.	Stone et al. (1975).
	Nickel	90%		
	Tungsten	66%		
	Moylbdenum	99%		
	DDT	98%	In laboratory tests, alum coagulation reduced concentrations of DDT 98% (with an influent concentration of 10 ug/l) and 97% (with an influent concentration of 25 ug/l).	Stone et al. (1975).

Table 18. (Continued)

Process	Contaminants	Removal efficiency	Comments	Reference
Coagulation (continued)	Aldrin	100%	$KMnO_4$ (1 mg/l) has been shown to oxidize and precipitate aldrin (in the sub mg/l range) completely in approximately 15 minutes.	Stone et al. (1975).
	Heptachlor	100%	Heptachlor (in sub mg/l quantities) was completely removed by 40 mg/l $KMnO_4$ in 5 hours.	Stone et al. (1975).
	Cobalt	88%	Lime reduced cobalt 88% with an influent concentration of 12 mg/l. Further details were not reported.	Stone et al. (1975).
	Molybdenum	10%	Molybdenum concentrations were reduced by only 10% by lime coagulation at a pH of 8.2.	Stone et al. (1975).
	Nickel	~100%	With an initial concentration of 160 mg/l, lime coagulation reduced nickel concentrations to 0.08 mg/l. Initial concentrations at 250 mg/l were reduced 99% at a pH of 9.9. Concentrations of 2,935 mg/l have been reduced below 1 mg/l.	Stone et al. (1975).
	Antimony	90%	Coagulation with lime; pH 11*.	Stone et al. (1975).
	Molybdenum	<10%	Coagulation with lime; pH 8.2*.	
	Cobalt	88%	Coagulation with lime; pH 9.5*.	
	DDT	98%	Coagulation with lime; initial concentration 10 mg/l*.	
	Dieldrin	55%	Coagulation with lime; initial concentration 10 mg/l*.	
	Endrin	35%	Coagulation with lime; initial concentration 10 mg/l*.	
	Lindane	<10%	Coagulation with lime; initial concentration 10 mg/l*.	
	Parathion	20%	Coagulation with lime; initial concentration 10 mg/l*.	
	Nickel	26%	Coagulation with alum.*	
	Vanadium	100%	Coagulation with alum performed at pH 8.5 and ratio of aluminum to vanadium of 50 to 100 (by weight). Tests with ferric chloride performed at pH of 8.5 - 9 and iron to vanadium ratio of 3 to 10. Chitosan said also to be effective; data not reported.	
	Methoxychlor	85 - 94%	Alum and ferric sulfate coagulation in jar (bench scale) tests. Initial turbidity of 23 NTU, pH range 4.5 to 8.5 with 30 mg/l coagulant dose.	Steiner and Singley (1979).

Table 18. (Continued)

Process	Contaminants	Removal efficiency	Comments	Reference
Activated carbon adsorption	PCBs	99%		Mitre (1978).
	TOC	70%	Pilot plant studies performed at Torresdale water treatment plant, Philadelphia, PA.	Yohe et al. (1981).
	p-dichlorobenzene	100%		
	Chloroform	0%	The adsorption breakthrough for chloroform occured very rapidly. Although some adsorption occurred during the first 3 weeks of tests, reduction by adsorption was not consistant for any significant length of time.	Yohe et al. (1981).
	1,2-bis(2-chloroethoxy)-ethane	100%	Breakthrough for contaminant was 6 weeks for an untreated column and 7 weeks for column treated with chlorine. Subsequent partial removals occurred with sporadic breakthroughs.	Yohe et al. (1981).
	Trichloroethylene	100%	During pilot scale tests complete removal (below detection) of contaminants was accomplished for approximately 30 weeks. Influent concentrations varied for each chemical (from 264 ug/l for 1,1,1-trichloroethane to 2 ug/l for trichloroethane. Detection limits were at least an order of magnitude below influent concentrations.	Roebeck and Love (1983).
	Tetrachloroethylene	100%		
	1,1-Dichloroethylene	100%		
	1,1 plus 1,2-dichloroethane	100%		
	1,1,1-trichloroethane	100%		
	Benzo(a)pyrene	99.8%	The removal efficiencies recorded with an influent of 100 ug/l. Further details were not reported.	NAS (1980)
	α-BCH	80%		
	Hexachloroethane	100%		
	Heptachlor epoxide	>80%		
	Methoxychlor	>80%		
	Polynuclear aromatic hydrocarbons	99%		
	Isopropyl ether	80%	Bench scale laboratory tests showed, "the lower the solubility of ether, the higher the adsorption." Increased pH tends to increase the capacity of the carbon.	Stone et al. (1975).
	Butyl ether	100%		
	Dichloroisopropyl ether	100%		

Table 18. (Continued)

Process	Contaminants	Removal efficiency	Comments	Reference
Activated carbon (continued)				
	Dieldrin	90%	1 hour contact time and carbon dose of 200 mg/l.	Stone et al. (1975).
	Chlordane	99%	Activated carbon dose of 10 mg/l.	
	Aldrin	90%	1 hour contact time and carbon dose of 100 mg/l.	
	DDT	90%	Lab scale tests using 10 mg/l activated carbon.	
	Lindane	90%	Lab scale tests using 10 mg/l activated carbon.	
	Parathion	100%	Lab scale test using 10 mg/l activated carbon.	
	Malathion	87.5%	Powdered activated carbon using 10 mg/l dose.	
Resin adsorption	cis-1,2-dichloro-ethylene 1,1,1-trichloroethylene Trichloroethylene	100% >80% 100%	Three resin columns were investigated with depths of 1, 2, and 4 feet. Flow was set at 21 gallons per hour. Removals for the 2 and 4 foot resin columns proved to last much longer with effluent levels below or close to detection limits. When the project ended the 4 ft column's efficiency was decreasing but still a 58% removal was observed. The resin system showed excellent removals for over 200 days with influent concentrations of over 200 ug/l and effluents of < 25 ug/l. The 4 ft column showed no efficiency loss up to the end of the project at 280 days. The resin columns explained above used a Rohm and Haas product (Ambersorb XE340) designed to remove relatively non-polar organic molecules and halogenated organics from water.	Ruggiero et al. (1980).
Coagulation, filtration, and sand filtration	Total organic carbon	15 - 64%	Compiled from North Carolina drinking water plant data. This information represents typical removals for drinking water plants using conventional water treatment practices of coagulation, floculation, filtration, and clear well storage.	Singer et al. (1981).

* Further details not reported in literature cited.

coagulation) are extremely sensitive to pH, with the optimum pH determined by the specific coagulant or oxidant added or adsorbant used (Weber 1972). The pH of water is usually adjusted, either by carbonation to decrease the pH (via carbonic acid formation) or by lime or soda ash addition to increase the pH, to bring the water near the optimum pH for the subsequent process(es). Coagulation is usually best achieved at alkaline pH; oxidation is also greatly favored at high pH (8 to 10 units or greater) (Weber 1972). These processes, when used, generally occur early in the water treatment scheme. The pH of the water may therefore be maintained at an alkaline pH through much of the treatment, then carbonated or otherwise neutralized prior to adsorption (if applied) or distribution. Adsorption is greatly favored at neutral or acidic pH (Weber 1972).

(1) Aeration. ASCE (1967) defines aeration in water treatment as "the process by which a gaseous phase, usually air, and water are brought into intimate contact with each other for the purpose of transferring volatile substances to or from the water." Translated into practical terms, aeration has two major applications:

- Removal of dissolved gases, such as hydrogen sulfide, carbon dioxide, methane, and volatile organic substances.
- Addition of oxygen for oxidation of reduced metals, such as ferrous iron.

Aeration is generally used for treatment of ground water. The natural reaction of flowing surface water effectively volatilizes the contaminants aeration is designed to strip (Clarke et al. 1977). Surface waters similarly do not retain reduced metals; they are naturally oxidized. An exception to this may be impoundments with anaerobic hypolimnions (Clarke et al. 1977). The metals and gases in ground water may, however, be amenable to oxidation or stripping (ASCE 1967).

Three types of aerators are commonly used (ASCE 1967):

1. Waterfall, cascade, or tray types, which work by creating numerous droplets of water, thus increasing the water surface-to-air volume ratio.
2. Diffusion aerators in which air is injected into the water in a tank.
3. Mechanical aerators, which employ motor-driven impellers alone or in conjunction with diffusers.

The first type is by far the most common in water treatment (Clarke et al. 1977). The third is common in wastewater treatment.

The use of multiple trays or cascades is effective in removing gases and oxidizing iron. Aeration is also called for when reduced manganese is present, but aeration must be accomplished in conjunction with chemical oxidation. Chlorine and potassium permanganate are commonly added (see Section 5.1.1(7)), and coke or stone in the trays also may aid removal.

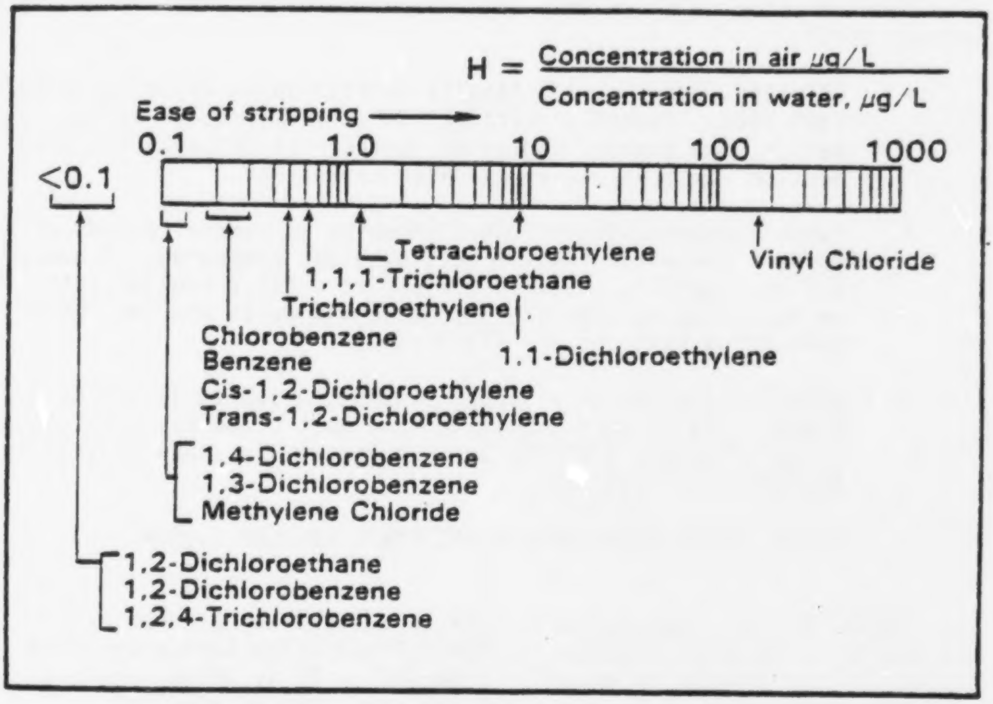
Aeration is an initial step in water treatment. It is generally followed by (optionally) chemical oxidation, then sedimentation and filtration. Criteria for use of aeration of ground waters include (ASCE 1967, Clarke et al. 1977):

- Carbon dioxide > 10 ppm
- Hydrogen sulfide > 1-2 ppm
- Iron > 0.3 ppm
- Manganese > 0.05 ppm
- Tastes and odors attributed to volatile organics.

Criteria also exist for avoiding the use of aeration:

- Aeration is not to be used in conjunction with ion exchange, since oxidized metallic compounds may foul the exchange resin (USGS 1964).
- Increased corrosiveness caused by addition of oxygen may cause problems in the distribution system (ASCE 1967).
- Aeration as a treatment step late in the sequence is to be avoided, as airborne contamination may be introduced with no means of effective removal prior to its introduction into the distribution system (ASCE 1967).

The efficiency of contaminant removal by aeration is summarized in Table 18. Removal via stripping may be predicted for specific compounds on the basis of chemical properties like Henry's law constant, as illustrated in Figure 13.


H = Concentration in air µg/L / Concentration in water, µg/L
Ease of stripping
0.1
1.0
10
100
1000
<0.1
Tetrachloroethylene
Vinyl Chloride
1,1,1-Trichloroethane
Trichloroethylene
Chlorobenzene
Benzene
1,1-Dichloroethylene
Cis-1,2-Dichloroethylene
Trans-1,2-Dichloroethylene
1,4-Dichlorobenzene
1,3-Dichlorobenzene
Methylene Chloride
1,2-Dichloroethane
1,2-Dichlorobenzene
1,2,4-Trichlorobenzene

Source: Love et al. 1983.

FIGURE 13. EASE OF STRIPPING AS A FUNCTION OF HENRY'S LAW CONSTANTS FOR SELECTED ORGANICS

(2) Chemical oxidation. This water treatment process involves the addition of strong oxidizing agents to break down chemical substances. Oxidizing agents are generally fed to the water near the beginning of treatment, prior to coagulation or softening.

Numerous chemicals are used as chemical oxidants (ASCE 1967, Clarke et al. 1977):

- Chlorine, when added initially in high doses of up to 30 mg/l (NAS 1982a) (prechlorination), oxidizes microbial cells, reduced metals, and organic compounds; breakpoint chlorination (see Section 5.1.1(9)), also oxidizes compounds.

- Potassium permanganate, when added up to concentrations of 10 mg/l in raw water (NAS 1982a), oxidizes compounds. A dosage of 0.5 to 2 mg/l is often sufficient to oxidize contaminants. The permanganate reduces the insoluble manganese dioxide, which is removed by settling and filtration.

- Chlorine dioxide is a strong oxidant, added to levels of 0.2 to 2 mg/l. It is more expensive than most oxidants, so although it is an effective disinfectant, it is usually added only at the beginning of treatment.

- Ozone, which forms highly efficient nascent oxygen.

Table 18 lists the available data on destruction by chemical oxidation. The effectiveness of chemical oxidation varies with the nature of the organic or metallic compounds. It is often possible, however, to predict removal by applying knowledge of chemical stoichiometry. For example, it is known that 1 mg/l of potassium permanganate will theoretically remove 1.06 mg/l iron or 0.52 mg/l manganese. Equations can be constructed for any combination of chemical oxidant and contaminant by simply applying the principles of balancing oxidation-reduction reaction equations.

Ozone (O_3) has been used for water treatment since 1903 (Houck et al. 1985); its use is widespread in Europe, but limited in the U.S. (Clarke et al. 1977). All its applications are related to its oxidizing ability (Weber 1972):

- Reduction of color

- Disinfection (bacterial and viral)

- Increased settleability

- Oxidation of organic materials (including phenolics, trihalomethane precursors, and algal biomass)

- Oxidation of reduced metals (iron and manganese) or cyanide.

Ozone for water treatment is produced by a high-voltage electrical discharge that splits the divalent oxygen molecules, leading to O_3 recombinations (Weber 1972). Ozone is generally unstable; once produced, it is immediately introduced into the water in a highly baffled mixing chamber (ASCE 1967). The large amount of electricity needed to generate usable concentrations of ozone (1% w/w) is the major factor in the currently prohibitive cost of this unit process for most water utilities.

Ozone is under increased scrutiny of late as an alternative to disinfection by chlorination. As discussed in Section 5.1.1(9), chlorination of naturally occuring organics during water treatment leads to the formation of trihalomethanes (THMs). At least one of these substances, chloroform, is considered by EPA a probable human carcinogen, necessitating a review of standard water treatment procedures. The use of ozone has two major advantages:

- Disinfection is achieved without THM formation, while adding the benefits of its other functions.

- Use of ozone is relatively cost effective when compared to the use of chlorination followed by activated carbon adsorption.

Ozone may be used as a pretreatment step prior to conventional coagulation-flocculation-filtration, as a pretreatment step in direct filtration, or as the final step before the water enters the treatment system (Houck et al. 1985). Addition of a low concentration of chlorine is, however, recommended to ensure sterile water throughout the distribution system (Clarke et al. 1977).

It should be noted that the term "chemical oxidation" encompasses the action of molecular oxygen in the aeration process (Section 5.1.1(1)).

(3) Coagulation and Flocculation. Coagulation and flocculation remove turbidity and the contaminants associated with it. Coagulation is the process that reduces the net repulsive forces between electrolytes in solution. Flocculation is defined as aggregation by chemical bridging between particles (Clarke et al. 1977). The two processes may be performed consecutively in separate basins or concurrently in one basin.

Stumm and O'Melia (1968) describe six steps in coagulation and flocculation; the steps are not discrete and may overlap.

1. Hydrolysis of multivalent metal ions and polymerization to multinuclear species.
2. Adsorption of hydrolysis products to accomplish destabilization of colloids.
3. Aggregation of destabilized particles by bridging.
4. Aggregation by particle transport and van der Waals' forces.
5. Aging of floc, involving bridge alterations and floc hydration.
6. Precipitation of metal hydroxide.

It is obvious that this treatment process is complex, and it is not fully understood. The action and effectiveness varies with the chemicals used and those to be removed (Clarke et al. 1977).

Coagulation involves coagulants and auxiliary compounds termed "coagulant aids." The most widely used coagulants are aluminum and iron salts: aluminum sulfate (alum), ferrous sulfate (copperas), ferric chloride, and ferric sulfate. Alum is added in the range of 5 to 150 mg/l, depending on the raw water chemistry; each mg/l of alum removes 0.5 mg/l of alkalinity (as $CaCO_3$). Copperas is used in conjunction with excess lime or chlorine. One mg/l removes 0.5 mg/l calcium carbonate in the lime-copperas treatment. The chlorine-copperas combination results in the formation of ferric sulfate and ferric chloride, which form insoluble hydroxide complexes with calcium (Clarke et al. 1977). Ferric chloride and ferric sulfate may be added directly at maximum levels of 60 and 100 mg/l, respectively.

Coagulant aids have many purposes (Clarke et al. 1977):

- Acids and alkalis are added as needed to adjust the pH for optimum coagulant action.
- Activated silica added to between 1 and 5 mg/l, has a strong negative charge. It reacts with positive metal hydroxides to stabilize the floc.

- Clays add weight and stability to floc. The amount used varies widely among water treatment plants, but usually does not exceed 15 mg/l (NAS 1982a).

- Polyelectrolytes increase the rate and degree of flocculation by adsorption, charge neutralization, and interparticle bridging. Dosages can range from less than 1 to 5 mg/l, though expense of the chemicals usually keeps the amounts small.

Synthetic polyelectrolytes are high-molecular-weight, water-soluble polymers (such as cross-linked styrenes, acrylamides, acrylates, phenols, and pyridines) that disassociate and produce highly charged ionic chains. The polymers may be cationic (positive), anionic (negative), or polyampholytic (both charges). Polyelectrolyte coagulation aids should be selected for use only after careful characterization of the water to be treated so that contaminants can be selectively removed (ASCE 1967).

Coagulants and auxiliary chemicals are added to the water in a flash-mixing basin (if coagulation and flocculation are separate) or in the coagulation-flocculation unit. After the chemicals have been added, the mixture is agitated slowly enough so that particles are formed, yet not destroyed by the mixing action. Flocculation can be achieved by use of paddles or the mixture can be forced to flow through baffled chambers (ASCE 1967).

Flocculation is followed by settling (see Section 5.1.1(4)) to remove the suspended floc. Table 18 presents data on the removal of some chemical constituents by coagulation and flocculation. These processes are inherent in the Type I filtration plant process scheme used for most surface waters, and with sedimentation, they characteristically effect nearly 100 percent removal of solids (measured as turbidity) (Clarke et al. 1977).

(4) Sedimentation. Sedimentation, the use of tanks to reduce the amount of settleable solids, is second only to chlorination and filtration in frequency of use in water treatment (ASCE 1967). Sedimentation basins are known variously as settling tanks, settling basins, or clarifiers. There are two basic applications of sedimentation in water treatment (ASCE 1967):

- Plain sedimentation, used to remove particulate that occurs naturally in surface water.

- Sedimentation following coagulation, designed to remove the floc created by flocculation of coagulants and water.

The effectiveness of a sedimentation tank depends on how well the tank was designed with respect to the characteristics of the solids to be removed. The geometry of the tank and the flow rate through the tank are the critical design considerations (ASCE 1967). Tanks may be round or rectangular; influent water is fed into the center of round tanks and flows outward, while in rectangular tanks, the water flows the length of the basin and out the end over weirs. Plain sedimentation tanks are generally rectangular. Clarifiers used after coagulation may be either shape.

The theory behind sedimentation following coagulation is complicated, involving the laws of physics and chemistry (Clarke et al. 1977, ASCE 1967). Gravity affects the rate at which particles move downward through water, as described by numerous equations including Stoke's Law.

Electronic charges on the surface of floc particles, measured by the zeta potential (Stumm and O'Melia 1968), cause two particles that contact each other to adhere and form one larger particle; the larger the particles are, the faster the rate of subsidence (Clarke et al. 1977).

The efficiency of sedimentation is directly related to the detention time in the basin. Engineers therefore design the sedimentation basin to hold water for a length of time sufficient to achieve the desired removal of solids. The nature of the particles to be removed determines the upper limit of efficiency; e.g., colloids are rarely removed by sedimentation, while dirt and sand are removed at up to 100 percent efficiency.

No data on the effect of sedimentation alone on contaminant removal have been identified.

(5) Lime-soda ash softening. The purpose of softening is to reduce a water's magnesium and calcium content. These cations, as discussed in Section 2, consume soap and cause scaling in piping and water heaters. Consumers generally object to water with hardness greater than 150 mg/l, expressed as calcium carbonate (Clarke et al. 1977). Such waters are usually softened.

Figure 14 displays the chemical reactions that achieve softening by the addition of lime ($Ca(OH)_2$) and soda ash (Na_2CO_3). Lime-soda ash softening also removes iron, manganese, strontium, and aluminum if sufficient quantities of the reactants are added (Clarke et al. 1977). The optimum concentrations of calcium and magnesium in the finished water are 75 to 85 mg/l and 20 to 40 mg/l, respectively (ASCE 1967).

(1) $CO_2 + Ca(OH)_2 = CaCO_3\downarrow + H_2O$

(2) $Ca(HCO_3)_2 + Ca(OH)_2 = 2\ CaCO_3\downarrow + H_2O$

(3) $Mg(HCO_3)_2 + Ca(OH)_2 = CaCO_3\downarrow + MgCO_3 + 2\ H_2O$

(4) $MgCC_3 + Ca(OH)_2 = Mg(OH)_2\downarrow + CaCO_3\downarrow$

(5) $MgSO_4 + Ca(OH)_2 = Mg(OH)_2\downarrow + CaSO_4\downarrow$

(6) $CaSO_4 + Na_2CO_3 = CaCO_3\downarrow + Na_2SO_4$

FIGURE 14. CHEMISTRY OF THE LIME-SODA PROCESS (CLARKE ET AL. 1977)

Apart from removal of divalent cations, lime-soda softening has numerous benefits. The addition of lime generally aids in coagulation, and the elevated pH that results from its use also provides a measure of disinfection (Clarke et al. 1977).

Variations of this process are in use throughout the United States:

- Excess lime treatment, in which lime above the stoichiometric level is added, reduces hardness to 30 mg/l of $CaCO_3$ and 10 mg/l of magnesium hardness. It is accomplished in two stages of lime addition, between which the water is recarbonated by bubbling in CO_2 (ASCE 1967, Clarke et al. 1977). The total lime dosage can range from 100 to 650 mg/l (NAS 1982a).
- Split treatment, in which a portion of the raw water is bypassed to reduce lime requirements and produce a moderately soft water, may involve softening of 50 to 90 percent of the influent water (ASCE 1967).

Lime-soda ash softening is used for most waters from which hardness must be removed; the alternative is ion exchange, which is more expensive and difficult to operate. Many ground waters and some surface waters are treated by lime-soda ash softening. Table 17 presents the frequency of use.

Lime-soda ash softening may result in the alkaline destruction of organics and precipitation of metal hydroxides as well as removal of hardness. The few data relevant to this are presented in Table 18.

(6) Direct filtration. Direct filtration refers to a system of treatment for water rather than a single unit process. In direct filtration, coagulants are flash-mixed with the raw water, then sent directly to sand filters. The sedimentation step, usually an important component in a filtration plant, is left out entirely because the floc are so small that they are effectively removed by filtration alone; sedimentation has little effect. Direct filtration therefore requires less capital investment and is under scrutiny for widespread application.

Some research on the efficiency of contaminant removal has been performed (see Table 18). Direct filtration is somewhat less effective than the complete complement of processes in a filtration plant. Most data are based on pilot plants; very few full-scale direct filtration plants are currently in use.

(7) Filtration. Water filtration through inorganic media is a physical and chemical process (ASCE 1967). It is simply defined as a process for clearing liquid of suspended material (USGS 1964). Sand is the usual filtration medium, and the gravity-flow rapid sand filter is the standard of the water industry (ASCE 1967). Filtration can be achieved by any of these media:

- Rapid sand filtration operates at high flow rates and comprises a simple medium (sand), with size gradation (fine to coarse) of the sand. It is generally used after coagulation and settling to remove nonsettleable floc (Clarke et al. 1977).
- Slow sand filtration is limited to waters of low turbidity, low color, and low microbial content. There is some biological action in the filter which may aid in the removal of organic compounds (USGS 1964).
- Diatomite filters are constructed with a layer of diatomaceous earth on top of a sand substrate. These filters are unstable and difficult to maintain; thus, their applicability is limited (ASCE 1967).
- Mixed media filters may incorporate strata of other materials, such as anthracite or garnet. Efficiency of contaminant removal exceeds that of regular sand filters (ASCE 1967).

Most filtration units operate in the same manner. Water is fed to the top of the filter (at varying rates) and flows downward through the sand grains. The pores between grains and attraction of van der Waals' forces trap contaminants in the filter (Clarke et al. 1977). When the filter becomes laden with floc particles, its efficiency decreases drastically and the filter bed is hydraulically expanded (back-washed); the water then washes out impurities and is drawn off. The filter bed again settles into its natural arrangement, with larger (heavier) grains at the bottom (ASCE 1967, Clarke et al. 1977).

Table 18 lists the data on removal of chemicals during filtration. Unless anthracite is incorporated into the filter, removal is limited to suspended constituents; dissolved ions are unaffected.

(8) Carbon adsorption. Adsorption is defined by Stone et al. (1975) as a surface phenomenon involving the accumulation of substances at a surface or interface between one phase and another. Adsorption from solution onto a solid results from two driving forces: a disaffinity of

the solute for the solvent, and an attraction between the solute and the adsorbent. In the case of adsorption on activated carbon, these forces are joined by an additional factor. Activated carbon is a porous substance, and large molecules (such as high molecular weight organics) are physically trapped in the carbon matrix. One pound of activated carbon has a surface area of over 100 acres (Clarke et al. 1977).

Activated carbon may be applied by either of two methods at a dosage usually not exceeding 200 mg/l (NAS 1982a): (Clarke et al. 1977, Stone et al. 1975):

- Batch contact, in which carbon is added (most often powdered, occasionally granular or pelletized) to the water (usually as a slurry). The adsorbent and the water are mixed, and the reaction is allowed to occur for a predetermined length of time (usually longer than 15 minutes and often up to 48 hours (Stone et al. 1975)). The water is then allowed to settle. Activated carbon may be added at any point prior to filtration.
- Column operation, in which water is filtered through fixed beds operated in series or parallel. Columns utilize granular activated carbon and operate at rates of 1 to 2 liters/second/m^2 with contact times ranging from 15 minutes to two hours.

Activated carbon adsorption is probably the most effective means of controlling organic compounds in water (Stone et al. 1975, Clarke et al. 1977). The cost of operating activated carbon columns can be, however, very high. Carbon can be exhausted after a few weeks of adsorption and must be replaced or regenerated. The bed life of carbon depends upon the water composition and the specific organic compound to be removed. Some systems using carbon for taste and odor control replace the carbon once or twice a year. Utilities trying to remove specific poorly adsorbed organics must replace or regenerate the carbon much more frequently. Heating the carbon to approximately 900°C will accomplish regeneration; however, large amounts of energy are required (Stone et al. 1975). Activated carbon is used mainly by water utilities as a last resort in treating organics; it is generally less expensive to use chemical oxidation or preventative methods. For example, utilities that prechlorinate water may experience problems with high concentrations of chlorinated organics. These could be removed by carbon adsorption, but they could be prevented by switching disinfectants (e.g., using chloramines) or chlorinating only the finished water after oxidation, coagulation, and filtration to reduce the precursor pool of organic reactants (NAS 1980).

The effectiveness of activated carbon is illustrated by the data in Table 18. The effectiveness of carbon adsorption is, however, best expressed in terms of isotherms, which take into account the solute concentration and the surface concentration at various points in time. A removal efficiency represents only one point on a compound's isotherm (NAS 1980). Adsorption is believed to be a step-wise process, whereby the least water-soluble solutes are removed from solution first (Weber 1972). There may therefore be relatively large differences in organic solute removal by carbon adsorption, as seen in the data in Table 18. All compounds studied to date are removed to some degree. Though there are no data on removal of heavy metals by carbon adsorption, Stone et al. (1975) believe that addition of a chelating agent (such as EDTA) to the water would produce an organometallic complex that would be absorbed by the carbon, ensuring nearly 100 percent removal.

One problem with activated carbon column adsorption is the tendency for organics to desorb from the column when the capacity has been exhausted. Compounds that have accumulated over the useful life of the column may appear in column effluent in a slug; this phenomenon, known as the chromatographic effect or breakthrough, can be prevented by monitoring and careful treatment planning and operation. A related difficulty in carbon bed operation is the tendency for organics to preferentially sorb and desorb on the carbon surface. This occurance is related to the differences in solubility discussed above (and other less well-understood factors). For example, substituted phenols will replace unsubstituted phenol and cause its rapid desorption (NAS 1980). Water to be treated must be fully characterized with regard to combinations of organics that may display this phenomenon.

The growth of microorganisms, particularly bacteria, on granular activated carbon beds has also been recognized as a problem as bacteria are washed out of the filter and because of the appearance of bacterial metabolites in filter effluent (NAS 1980). Since that first recognition that bacteria can live in GAC filters, other investigators (most recently Neukrug et al. 1982) have studied the effect of bacterial decomposition of organics by the combined bacterial-carbon action (termed biological activated carbon, or BAC). The control of the microorganisms in the carbon bed was found by Neukrug et al. (1982) to be not worth the effort required to achieve biologically-mediated, effective organics removal. Other investigators feel BAC holds promise, as it has been used in Europe for several years.

Other adsorbents have been shown to be as effective as activated carbon; some are more efficient in removing selected contaminants (see Table 18). Synthetic organic polymers (e.g., XAD, Amberlite, polyurethane) show great promise but are not yet economically feasible.

(9) Chlorination. Chlorine is added to public drinking water supplies primarily to prevent the spread of waterborne disease; additional benefits include oxidation of organic and metallic contaminants and control of nuisance microbial growth in the water treatment plant and distribution system (Sawyer and McCarty 1978, Clarke et al. 1977). Chlorination has been practiced as an emergency measure since 1850, and regularly in the U.S. since the early 1900s (Sawyer and McCarty 1978). The vast majority of waters that are treated before consumption are chlorinated (see Table 17).

Chlorine may be added to water in a number of forms; chlorine gas, hypochlorites, chloramines, and chlorine dioxide are the major compounds used (Clarke et al. 1977). Chlorine gas and hypochlorites function by the formation of hypochlorous acid, the primary disinfecting agent (Sawyer and McCarty 1978).

The significant aspect of chlorination with regard to exposure to toxic substances is the reactivity of chlorine with a wide variety of chemicals. Chlorine reacts with ammonia to form chloramines, non-toxic compounds with sufficient disinfecting power for use in public water supplies (Sawyer and McCarty 1978). Chlorine also reacts with hydrogen sulfide, iron, manganese, and nitrogen oxides. In order to ensure sufficient chlorine dosage to retain a residual level through the distribution system, a practice known as breakpoint chlorination is common. In this process, the combined chlorine content is measured, then additional chlorine to fully oxidize the compounds is added. This often requires heavy chlorine dosages (over 10 mg/l) (Clarke et al. 1977, Sawyer and McCarty 1978).

The formation of chlorinated organics during water treatment has been well studied. Among the factors affecting the extent of chlorinated organics formation are:

- Point of chlorine application. Chlorination at the beginning of treatment to control algal growth in the system (prechlorination) allows chlorine to react with organic compounds in the raw water. If chlorination is used only as a final step, many organic molecules that would have reacted will have been removed by coagulation, filtration, etc.

- The amount and type of organics in the water. Phenols are readily chlorinated, as are simple sugars and acids. Simpler organic compounds, when chlorinated, form trihalomethanes (THMs). Chloroform is the most common THM formed during water treatment, and because of chloroform's carcinogenicity to animals, THMs are now regulated by EPA (see Section 2). If bromide is present in the water that is to be chlorinated, brominated organics are also formed (Sawyer and McCarty 1978).

- The pH and temperature at which the reaction occurs. Chlorination at high pH, such as is present in lime-soda softening plants, increases the reaction rate (Stevens et al. 1976). THM concentrations are generally higher in the summer (Brett and Caverly 1979, Smith et al. 1980).

A large number of organic compounds have been examined for their ability to serve as THM precursors. The most commonly recognized precursors are humic and fulvic acids, the naturally-occurring compounds in peat and vegetation that give surface waters their characteristic brown-yellow coloring. Rook (1972) and Bellar et al. (1974) were the first to demonstrate THM formation from chlorination of surface waters. Since that time, polyelectrolyte coagulants (Littlefield 1979), algal byproducts (Morris and Baum 1978, Hoehn et al. 1980), and algal and bacterial biomass (Hoehn et al. 1980) have been shown to produce THMs when chlorinated. Some reduction in formation of THMs has been noted when chlorine dioxide or chloramines are substituted for gaseous chlorine and hypochlorites in disinfection (Hoehn and Randall 1977, Symons et al. 1975).

Ingestion of chlorinated organics as a result of drinking water treatment affects primarily persons consuming treated surface waters. The organic precursor molecules usually occur naturally in lakes, reservoirs, and rivers and are not often found in ground water.

Though some chlorination practices are known to cause formation of chlorinated organics, it is not likely that chlorine, chloramines, and chlorine dioxide will be abandoned. They are the only disinfectants that persist through the treatment and distribution system, minimizing the risk of contamination before the water reaches the consumer. Water utilities experiencing problems with chlorinated organics generally try to remove the organics from the water prior to chlorination; if THMs or other compounds are still a problem, carbon filtration or resin adsorption may be used as a final treatment step.

(10) Fluoridation. Most public water supply systems add fluoride ion as a final step in the treatment process. Over 37 thousand tons of fluoride compounds were consumed by water utilities in 1981 (Nebel 1982). At an optimum level of 1.0 mg/l, fluoride has been shown to significantly reduce the incidence of dental caries; an additional

benefit of increased fluoride intake may be the prevention of osteoporosis and arterioscelerosis in the elderly (Clarke et al. 1977).

Fluoride is commonly applied in the following forms (Clarke et al. 1977):

- Sodium fluoride, a crystalline salt that can be handled manually.
- Sodium silicofluoride, applied by dry feeder and the most commonly used compound.
- Fluosilicic acid, a strong acid requiring great care in handling; used mainly by very large water works.

Less commonly-used fluoridating chemicals include ammonium silicofluoride and fluorspar (CaF_2) (ASCE 1967). The chemicals may be fed into a channel or main leading from the water filters or added directly to the water in its storage tank or clearwell.

Some water supplies are derived from sources naturally rich in fluoride due to geological formations. Consumption of water with a fluoride concentration greater than 2 mg/l may result in discoloration (mottling) or pitting of tooth enamel, occasionally leading to loss of teeth (Clarke et al. 1977, USGS 1964). Many utilities have replaced their high-fluoride supplies; the alternative is an additional treatment process. Reduction in fluoride concentration may be achieved by filtration through bone char or activated alumina (Clarke et al. 1977, ASCE 1967). These filtering media cannot be combined with sand, gravel, or carbon in mixed media filters, because the regeneration of bone char and activated alumina require backwashing with caustic solution, which may damage the more conventional media.

It has been shown that the presence or addition of other halogens (i.e., chlorine and bromine) leads to the formation of halogenated organics. The reactions between fluorine and organics have not been studied.

Many of the fluoride compounds used in water treatment are byproducts of other mineral mining. For example, fluorspar is manufactured from the waste of phosphate mining (NAS 1971). Concern for the purity of these chemicals has led to the inclusion of sodium fluoride and sodium silicofluoride in the National Academy of Science's Water Treatment Chemicals Codex (Rehwoldt 1982). The Codex recommends limits of impurities based on existing Maximum Contaminant Levels (MCLs), recommended use patterns, and safety factors; the guides have been formulated only for direct additives, but future expansion is planned.

5.1.2 Addition of Contamination During Water Treatment and Distribution

(1) Water treatment. The National Academy of Science (NAS) formed the Committee on Water Treatment Chemicals to investigate the addition to finished water of harmful chemicals that are impurities in water treatment aids. Table 19 summarizes the results of their initial efforts to control exposure to these impurities.

The committee calculated the Recommended Maximum Impurity Content (RMIC) for each impurity expected in each water treatment chemical. The following formula was used:

$$\text{RMIC} = \frac{\text{MCL or SNARL}}{\text{Maximum dosage x safety factor}}$$

Where maximum dosage was based on the committee's knowledge of use patterns, the safety factor was 10, and the MCL or SNARL (Suggested No-Adverse Reponse Level) was obtained from EPA or NAS data (Rehwoldt 1982). The safety factor is intended to take into account the use of more than one water treatment chemical containing an impurity as well as other exposure routes.* The NAS proposes to expand the codex to address some direct additives, such as polyelectrolytes, in a methodology-oriented fashion and others in the current monograph style.*

(2) Distribution system's effects on chemical quality. Within the distribution system, changes in water's chemical quality can result from corrosion, deposition, leaching, and reactions involving water treatment chemicals and their residuals (NAS 1982b).

Components of pipes or linings that may enter the water as it passes through are a common source of chemical contamination. Table 20 lists the contaminants related to water distribution systems and records some of the levels measured in tap water.

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*Personal communication between Robert Rehwoldt, NAS, and Gina Hendrickson, Versar, June 17, 1984.

Table 19. Summary of Water Treatment Chemicals CODEX

Chemical	Function	Maximum dosage, mg/l	Impurity	RMIC*, mg/kg
Aluminum sulfate (alum)	Coagulant	150	Arsenic	30
			Cadmium	7
			Chromium	30
			Lead	30
			Mercury	1
			Selenium	7
			Silver	30
Ammonium sulfate	Combined chlorine disinfection	25	Arsenic	200
			Pyridine	50
			Selenium	40
			Lead	200
			eem**	30
Calcium hydroxide (lime)	Softening, pH adjustment	650	Arsenic	10
			Cadmium	2
			Chromium	10
			Lead	10
			Selenium	2
			Silver	10
Calcium hypochlorite	Disinfection, oxidation	20	Mercury	10
Calcium oxide (quicklime)	Softening pH adjustment	500	Arsenic	10
			Cadmium	2
			Chromium	10
			Lead	10
			Selenium	2
			Silver	10
Powdered/granular activated carbon	adsorbent	200	Arsenic	30
			Chromium	30
			Lead	30
			Mercury	1
			Silver	30
Chlorine	Disinfection, oxidation	30	Carbon tetrachloride	100
			Trihalomethanes	300
			Mercury	7

Table 19. Summary of Water Treatment Chemicals CODEX (continued)

Chemical	Function	Maximum dosage, mg/l	Impurity	RMIC*, mg/kg
Ferric chloride	Coagulant	60	Arsenic	80
			Cadmium	20
			Chromium	80
			Lead	80
			Mercury	3
			Selenium	20
			Silver	80
Ferric sulfate	Coagulant	100	Arsenic	50
			Cadmium	10
			Chromium	50
			Lead	50
			Mercury	2
			Selenium	10
			Silver	50
Ferrous sulfate	Coagulant	80	Arsenic	60
			Cadmium	10
			Chromium	60
			Lead	60
			Mercury	3
			Selenium	10
			Silver	60
Potassium permanganate	Oxidant	10	Cadmium	100
			Chromium	500
			Mercury	20
Sodium aluminate	Coagulant	40	Arsenic	100
			Cadmium	30
			Chromium	100
			Lead	100
			Mercury	5
			Selenium	30
			Silver	100

Table 19. Summary of Water Treatment Chemicals CODEX (continued)

Chemical	Function	Maximum dosage, mg/l	Impurity	RMIC*, mg/kg
Sodium carbonate (soda ash)	pH adjustment	100	Chromium Lead	50 50
Sodium chlorite	ClO_2 production	10	Mercury Selenium	20 100
Sodium hydroxide	pH adjustment	100	Mercury	2
Sodium metabisulfite, sodium pyrosulfate	Cl removal	15	Arsenic Selenium	300 70
Sulfur dioxide	Cl removal	10	Arsenic Selenium	500 100
Sulfuric acid	pH adjustment	50	Selenium	20

*RMIC = recommended maximum impurity content.

**eem = ether extractable material.

Source: NAS 1982a.

Table 20. Contaminants That May Be Introduced in the Distribution System

Component	Contaminant	Measured levels
Steel mains	Iron	0.18 - 10.2 mg/l
Lead piping	Lead	0.03 - 1.5 mg/l
"Metal" pipe	Cadmium	[a]
	Chromium	[a]
	Manganese	[a]
	Zinc	[a]
	Nickel	[a]
	Cobalt	[a]
	Silver	[a]
Copper pipe	Copper	0.18 - 2.3 mg/l
Asbestos-cement pipe	Asbestos	not detected - >500 x 10^6 f/l
Plastic pipe (PVC) and linings	Vinyl chloride	<0.03 - 1.3 ug/l
	Metallic pigments and lubricants	[a]
Plastic pipe solvents	Methyl ethyl ketone, cyclohexanone, tetrahydrofuran N,N-dimethyl formamide	0.11 - 375 mg/l (total solvent)
Coal tar and asphalt lining	PAHs including: phenanthrene, anthracene, fluoranthene, pyrene, methyl pyrene, benzo(a)pyrene, benzo(ghi)perylene, indeno(1,2.3-cd) pyrene, dibenzo(a,h)-anthracene	<10 ng/l to 290 ug/l

[a] Representative quantitative data not available, but increase in concentration within distribution system noted.

Source: NAS 1982b.

Chlorination of finished water, discussed in the previous section, can result in the formation of chlorinated organics. Trihalomethanes (THMs) are formed both instantaneously and during the time the water travels between the water treatment plant and the consumer's tap. Samples at the tap may have twice the THM content of the water leaving the plant (NAS 1982b). Other chlorinated organics have been detected in tap water and attributed to the chlorine-organic reaction: chlorinated phenols, simple acids, polynuclear aromatic hydrocarbons, and benzenes (NAS 1982b). An exposure assessment for any chlorinated chemical species should take into account the possibility that formation in water treatment may be a source of exposure.

5.1.3 Determination of Finished Water Quality

There are two basic components to the use of the data in this section to determine whether water treatment affects the presence of a chemical, and if so, what the effect is:

- Defining the individual and combined processes used in treating drinking water.

- Determining whether data are sufficient to support a prediction of the occurrence or extent of chemical removal by water treatment.

The Federal Reporting Data System (FRDS) contains information on the types of treatment used by each water supply system in the U.S. For any water supply system, therefore, the assessor may retrieve data from FRDS on the unit processes used. From information presented in Sections 2 and 5.1.1 on the probable sequence of processes, treatment schemes may be reconstructed. Table 17 lists the treatment processes covered in the FRDS; some processes important in terms of contaminant removal, such as carbon adsorption, are conspicuously missing.

In the absence of specific data on processes used, a more general approach may apply. That approach entails the assumption that:

- Ground waters are treated by aeration, lime-soda softening, filtration, and chlorination - if they are treated at all.

- Surface waters are treated by presedimentation, coagulation, flocculation, sedimentation for floc removal, filtration, and chlorination.

The data in Table 18 may be used to indicate, qualitatively, whether removal may be expected for some types of chemicals and, in the case of the specific substances listed, the efficiency of removal. If removal efficiency data are not available for a substance being assessed, quantitative results of treatment can be predicted only if removal is closely associated with chemical properties (e.g., removal via aeration is related to a substance's volatility, as described by Henry's Law constant). Otherwise, further study of the effects of treatment are indicated. If, however, data on process-by-process removal (such as those in Table 18) are available, the calculation of finished water concentrations is straightforward:

$$C_F = C_R - \sum_{i=1}^{n} C_i \times R_i$$

where

C_F = finished water concentration

C_R = raw water concentration

C_i = concentration prior to entering treatment i

R_i = removal effected by treatment i

Calculation of finished water concentrations may not, however, accurately represent the concentrations at the user's tap. Chlorinated organics formed as a result of drinking water disinfection have been shown to increase through the distribution system (Smith et al. 1980). This is due to the fact that the haloform reaction (and similar reactions) may take hours, and chlorination just prior to discharge does not allow the reaction to become complete in the treatment system.

Two additional types of toxic contamination may occur in the distribution system; both are related to structural components. Metals may be dissolved from iron, steel, or copper pipe, especially if the water is corrosive. Piping constructed of polyvinyl chloride (PVC) is used in homes and in rural community systems. Pipe joints are glued together, and water may leach adnesives and solvents over time. There is, however, no means of quantifying distribution system effects at this time. Examination of monitoring data for finished water at the treatment plant and water in the distribution system may provide, if only qualitatively, the necessary information for a particular substance.

5.2 Private Systems

Private drinking water systems are often used by individuals residing in areas of low population density or in other areas where no public drinking water supply is available. The potential for exposure to chemical substances in private drinking water supplies may be greater than for individuals supplied by public drinking water. In a public water system, the finished water is routinely monitored to determine whether suspected chemicals are present. In a private water system, monitoring of water for potential contaminants is the responsibility of the individual using the supply.

It is possible for an individual to install a private water supply without ever conducting a sanitary survey of the potential water source. It is not uncommon for individuals to contact a health or environmental agency to complain about illnesses in the family or strange odors or tastes in the water only to find that their drinking water source is located too close to a source of contamination. Although state health departments and the Environmental Protection Agency (EPA) have established guidelines for selection of suitable private drinking water sources, it is the responsibility of the installers of the private drinking water supply to follow these guidelines. The most important guidelines for selection of suitable private drinking water sources are presented in Section 5.2.1.

The concentration of a chemical substance in finished drinking water from a private supply is determined not only by the proximity of the water to a source of contamination, but also by the efficiency of any treatment system in removing chemical substances. Several alternatives for home drinking water treatment are available. In Section 5.2.2, information on home drinking water treatment systems is presented. The selection of a home drinking water treatment system is determined primarily by chemical substances present in the water supply and by the cost an individual is willing to bear.

5.2.1 Guidelines for Selection of Suitable Private Drinking Water Sources

Guidelines for the selection of a suitable private drinking water supply have been outlined for ground water supplies and surface water supplies by the EPA's Office of Drinking Water. Table 21 lists the essential factors that should be considered in a sanitary survey of ground water supplies; Table 22 lists factors for surface water supplies (USEPA 1974).

Table 21. Essential Factors That Should Be Considered in a Sanitary Survey of Ground Water Supplies

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- Character of local geology; slope of ground surface.
- Nature of soil and underlying porous strata; whether clay, sand, gravel, rock (especially porous limestone); coarseness of sand or gravel; thickness of water-bearing stratum; depth to water table; location, log, and construction details of local wells in use and abandoned.
- Slope of water table, preferably as determined from observational wells or as indicated, presumedly but not certainly, by slope of ground surface.
- Extent of drainage area likely to contribute water to the supply.
- Nature, distance, and direction of local sources of pollution.
- Possibility of surface-drainage water entering the supply and of wells becoming flooded; methods of protection.
- Methods used for protecting the supply against pollution by means of sewage treatment, waste disposal, and the like.
- Well construction:
  1. Total depth of well.
  2. Casing: diameter, wall thickness, material, and length from surface.
  3. Screen or perforations: diameter, material, construction, locations, and lengths.
  4. Formation seal: material (cement, sand, bentonite, etc.), depth intervals, annular thickness, and method of placement.
- Protection of well at top: presence of sanitary well seal, casing height above ground, floor, or flood level, protection of well vent, protection of well from erosion and animals.
- Pumphouse construction (floors, drains, etc.), capacity of pumps, drawdown when pumps are in operation.
- Availability of an unsafe supply, usable in place of normal supply, hence involving danger to the public health.

Source: USEPA 1974.

Table 22. Essential Factors That Should Be Considered in a Sanitary Survey of Surface Water Supplies

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- Nature of surface geology: character of soils and rocks.
- Character of vegetation, forests, cultivated and irrigated land, including salinity, effect on irrigation water, etc.
- Population and sewered population per square mile of catchment area.
- Methods of sewage disposal, whether by diversion from watershed or by treatment.
- Character and efficiency of sewage-treatment works on watershed.
- Proximity of sources of fecal pollution to intake of water supply.
- Proximity, sources, and character of industrial wastes, oil field brines, acid mine waters, etc.
- Adequacy of supply as to quantity.
- For lake or reservoir supplies: wind direction and velocity data, drift of pollution, light intensity data (algae).
- Character and quality of raw water: coliform organisms (MPN), algae, turbidity, color, objectionable mineral constituents.
- Nominal period of retention in reservoir or storage basin.
- Probable minimum time required for water to flow from sources of pollution to reservoir and through reservoir intake.
- Shape of reservoir, with reference to possible currents of water, induced by wind or reservoir discharge, from inlet to water-supply intake.
- Protective measures in connection with the use of watershed to control fishing, boating, landing of airplanes, swimming, wading, ice cutting, permitting animals on marginal shore areas and in or upon the water, etc.
- Efficiency and constancy of policing.
- Treatment of water: kind and adequacy of equipment; duplication of parts; effectiveness of treatment; adequacy of supervision and testing; contact period after disinfection; free chlorine residuals carried.
- Pumping facilities: pumphouse, pump capacity and standby units, storage facilities.

Source: USEPA 1974.

When a properly constructed well penetrates an unconsolidated formation with good filtering properties, and when the aquifer itself is separated from sources of contamination by impervious materials, research and experience have demonstrated that 50 feet is an adequate distance separating a contamination source and a well (USEPA 1974). In cases where sources are severely limited, however, a ground water aquifer that might become contaminated may be considered for a water supply if treatment is provided (USEPA 1974). Lesser distances should be accepted only after a comprehensive sanitary survey, conducted by qualified state or local health agency officials, has satisfied the officials that such lesser distances are both necessary and safe. Conditions that are unfavorable to the control of contamination and that may require specifying greater distances between a well and sources of contamination are presented in Table 23.

5.2.2 Home Drinking Water Treatment Systems

The systems most frequently available for use in treating drinking water in the home include (1) filtration units containing activated carbon; (2) distillation units; and (3) water softening units. Other less frequently used systems available for treating drinking water in the home include reverse osmosis units, magnetic units, ozonator carbon units, and units that combine ultraviolet light with activated carbon. All of these systems can be installed by users of private or public water supplies. Information on filtration units containing activated carbon is presented in Subsection 5.2.2(1). Information on distillation units is presented in Subsection 5.2.2(2), and information on water softeners is discussed in Subsection 5.2.2(3). Lesser-known systems available for home water treatment are discussed in Subsection 5.2.2(4).

(1) Home drinking water treatment units containing activated carbon for organics reduction. Filtration units containing activated carbon are of several types. These types include: (1) pour-through, (2) faucet bypass, (3) faucet no-bypass, (4) stationary, and (5) line bypass (Changing Times 1981). Pour-through units are portable and require no installation. The user holds the filter over a receptacle and pours tap water into the top. Faucet filters are of two designs and fit onto the mouth of the tap. The faucet bypass design has a bypass valve which allows water used only for cooking and drinking to be filtered, thereby prolonging the life of the filter. The faucet no-bypass design filters all water that flows through the tap. Stationary types are tapped into the cold water pipe under the sink so that all the water flowing through the pipe is filtered. Line bypass types are also installed by cutting into the water line beneath the sink, but they use a separate faucet attached to the sink to deliver filtered water for drinking and cooking. Unfiltered water can still be drawn from the regular faucet.

Table 23. List of Conditions Unfavorable to the Control of Contamination and That May Require Specifying Distances Greater than 50 Feet for Siting of Wells

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- Nature of the contaminant. Human and animal excreta and toxic chemical wastes are serious health hazards. Salts, detergents, and other substances that dissolve in water can mix with ground water and travel with it. They are not ordinarily removed by natural filtration.

- Deeper disposal. Cesspools, dry wells, disposal and waste injection wells, and deep leaching pits that reach aquifers or reduce the amount of filtering earth materials between the wastes and the aquifer increase the danger of contamination.

- Limited filtration. When earth materials surrounding the well and overlying the aquifer are too coarse to provide effective filtration - as in limestone, coarse gravel, etc. - or when they form a layer too thin, the risk of contamination is increased.

- The aquifer. When the materials of the aquifer itself are too coarse to provide good filtration - as in limestone, fractured rock, etc. - contaminants entering the aquifer through outcrops or excavations may travel great distances. It is especially important in such cases to know the direction of ground water flow and whether there are outcrops of the formation (or excavations reaching it) "upstream" and close enough to be a threat.

- Volume of waste discharged. Since greater volumes of wastes discharged and reaching an aquifer can significantly change the slope of the water table and the direction of ground water flow, it is obvious that heavier discharges can increase the threat of contamination.

- Contact surface. When pits and channels are designed and constructed to increase the rate of absorption - as in septic tank leaching systems, cesspools, and leaching pits - more separation from the water source will be needed than when tight sewer lines or waste pipes are used.

- Concentration of contamination sources. The existence of more than one source of contamination contributing to the general area increases the total pollution load and, consequently, the danger of contamination.

Source: USEPA 1974.

According to Russo (1978), filtration units containing activated carbon remove algae, carbon tetrachloride, chlorine, chloroform, dirt particles, hydrogen sulfide, iron in suspension (rust), and sulfur. The effectiveness and longevity of a carbon filter depend partly on its design, the quality and amount of filtering material, the volume of water passing through it, and the length of time the water is in contact with the filter. The efficiency of 31 carbon filtration units in removing trihalomethanes (THMs) and non purgeable total organic carbons (NPTOCs) was tested for the EPA, Office of Drinking Water (ODW), by Gulf South Research Institute. Trihalomethanes are formed by the reaction of chlorine with organic materials in water. NPTOCs include harmless organic matter as well as residues of DDT and other pesticides. Most of the units tested are designed to do nothing more than improve the water aesthetically by removing taste and odor, but they were tested for THM and NPTOC removal anyway. The water used in the study was New Orleans city tap water from the Mississippi River, chosen partly because of the challenge its array of pollutants and organic materials presented to the filters (Changing Times 1981; USEPA 1980b). Table 24 presents the results of these tests regarding the efficiency of home filters in removing THMs and NPTOCs according to type of activated carbon treatment unit. In general, the line bypass types of activated carbon units were the most efficient in removing THMs and NPTOCs.

In another phase of the study, four tests were conducted to determine the effectiveness of home drinking water treatment units containing activated carbon in removing organics (USEPA 1982c). The first test was conducted using ground water samples spiked with four organic compounds. The second test was conducted to evaluate the effects of differing water quality on the performance of typical carbon units. Four home water treatment models were tested using the drinking water in four cities: Miami, Florida; Pico Rivera, California; Atlanta, Georgia; and Detroit, Michigan. The third test was conducted to evaluate the performance of units under nonaccelerated home use conditions. Three filter types of activated carbon units were tested with New Orleans tap water in three different homes. The fourth test was conducted using surface water samples spiked with the four organics used in the ground water test and three pesticides.

The results of the tests to determine the effectiveness of home units in reducing levels of four organic compounds in spiked ground water samples are presented in Table 25. Carbon tetrachloride reduction ranged from 55 percent for a faucet-mount unit to 99 percent for four-line bypass units. Trichloroethylene reduction ranged from 70 percent for a faucet-mount unit to 99 percent for four line-bypass units. Tetrachloroethylene reduction ranged from 62 percent for a faucet-mount

Table 24. Efficiency of Home Drinking Water Treatment Units Containing Activated Carbon in Removing Trihalomethanes (THMs) and Nonpurgeable Total Organic Carbon (NPTOCs)

Type	Product	Test life (gallons)	Average reduction, % THM	Average reduction, % NPTOC
Pour-through	Filbrook Pour-Thru Activated Carbon	1,000	40*	14
	H_2OK Portable Drinking Water Treatment Unit	2,000	19	10
	Puriton Bacteriostatic Drinking Water Treatment Unit	1,000	21	6
Faucet bypass	Aquaguard, Model AGT-31 Cartridge T-3XL	500	43	12
	Concept Bacteriostatic Home Water Filter	40	16	18
	Filter Fresh Model FF-1	1,200	6	6
	Hurley Town and Country	4,000	69	31
	Instapure Model F1-C	200	24	11
	Water Washer, Countertop Model 1000	1,000	41	11
Faucet no-bypass	Mini Aqua Filter	200	6	2
Stationary	AMF-Cuno Housing 1M Cartridge AP-117	3,000	34	7
	Filterite, Model 1 PC Cartridge 1C-9	3,000	18	8
	Fulfo Water Filter Model WC-10	3,000	15	11
	Keystone Model 3121 Housing with Model 310 Cartridge	3,000	21	9
	Sears Taste and Odor Filter	3,420	46	12

Table 24. (continued)

Type	Product	Test life (gallons)	Average reduction, % THM	Average reduction, % NPTOC
Line bypass	Aquacell Bacteriostatic Water Treatment Unit	2,000	86	23
	Aqualux Water Processor, Model CB-2	2,000	98	23
	Aqualux Water Processor, Model HB	2,000	45	28
	Argenion Bacteriostatic Water Treatment Unit, Model 1	2,000	23	—
	Continental Water Filter, Model 350**	720	99	87
	Culligan Super Guard, Model SG-2	4,000	89	28
	Everpure, Model QC4-THJM	1,000	99	55
	Mariner Renaturalizer Water Units	3,000	47	21
	Polarisdynamic Water Unit	2,500	61	18
	Purogen Water Detoxifier	2,500	38	6
	Seagull IV	1,600	70	30
	System 1 Water Processor, Model SY1-34	2,500	43	20
	Ultrapure Bacteriostatic	3,000	40	20
	Waterco, Model AS-5	3,000	25	--

Table 24. (continued)

Type	Product	Test life (gallons)	Average reduction, % THM	NPTOC
Others	Rohm and Haas Ambersorb XE-340***	3,500	93	6
	Wunderbar Portable Water Cleaner-Filter	200	4	--

* According to EPA the Filbrook was tested for 1,000 gallons, based on comparable life to other pour-through units. However, EPA says that sales literature can be interpreted to indicate a lifetime of 300 gallons, for which the average reduction would be 74%.

** Not widely available.

*** Experimental

-- Information not available

Source: USEPA 1980b.

Table 25. Range of Percent Specific Halogenated Organic (HO) Reduction for Line Bypass, Faucet-Mount, Stationary, and Pour-Through Units in the Ground Water Study

Unit	Rated capacity (gallons/liters)	Range of average percent HO reduction*			
		1	2	3	4
Line Bypass					
Aqualux CB-2	2000/7571	99-99	98-86	99-99	99-99
Continental Model 350	720/2725	99-99	99-99	99-99	99-99
Culligan Model SG-2	4000/15142	99-98	99-98	99-99	99-99
Everpure QC4-THM	1000/3785	99-99	95-99	99-99	99-99
Seagull IV	1000/3785	98-95	98-97	98-97	98-97
Aquacell	2000/7571	99-93	99-95	99-98	99-97
Faucet-Mount					
Hurley Town and Country	4000/15142	99-93	97-94	99-98	99-99
Water Washer Model 1000	1000/3785	96-40	95-55	95-70	99-62
Pour-Through					
Filbrook**	300/1136	99-72	98-82	95-94	99-98
Stationary					
Sears Taste and Odor	3000/11356	98-70	98-80	99-96	99-98

1 1,1,1-Trichloroethane
2 Carbon tetrachloride
3 Trichloroethylene
4 Tetrachloroethylene
* Range in reduction indicates gradual decline in effectiveness with time; best removals were obtained when filter was first installed.
** Filbrook was tested for 500 gallons, but results are adjusted to 300 gallons as being more representative of claimed lifetime.

Source: U.S. EPA 1982c.

unit to 99 percent for four line-bypass units. 1,1,1-Trichloroethane reduction ranged from 40 percent for a faucet-mount unit to 99 percent for three line-bypass units.

The results of the tests to evaluate the effects of differing water quality on the performance of typical carbon units yielded filter efficiencies for reducing THMs and NPTOCs comparable to laboratory tests with New Orleans drinking water. The USEPA (1982c) reported that the field test tends to confirm the validity of the central laboratory testing as being generally representative of a unit's performance on various waters.

The results of the tests to evaluate the performance of typical activated carbon units for removal of THMs and NPTOCs under nonaccelerated home use conditions were similar to the GSRI laboratory results obtained with New Orleans drinking water, with the exception of one unit which gave lower results in the home test for THM reduction. USEPA (1982c) reported that the home tests generally confirmed the validity of laboratory testing as representing efficiencies and conditions obtained under actual use conditions in a home.

The results of the test to determine the effectiveness of home units in reducing the levels of four organics and three pesticides in spiked surface water samples are questionable. These data are presented in Table 26. USEPA (1982c) reports that data for reductions of three pesticide chemicals were probably indicative of the value of activated carbon units for reducing these chemicals.

A factor not considered in the GSRI studies performed by EPA is the desorption of organics by activated carbon filters. This "chromatographic effect," or breakthrough, commonly occurs soon after the capacity of the adsorbant has been exhausted (Taylor et al. 1979). The chromatographic effect has been well documented in full-sized columns, but has not been studied extensively in home filters. It is believed by Taylor et al. (1979) and others that homeowners not replacing filter cartridges as often as recommended may receive exposure to organic chemicals at levels higher than those in the water prior to treatment.

(2) Home Distillation Units. Distillation is another method that can be used in home water treatment to remove undesirable substances. During the process of distillation, one liquid is separated from another liquid or solid by way of vaporization and condensation. The boiling water vaporizes leaving behind most of the solids previously contained in the liquid. The mere separation of liquids from solids does not require a very complex distillation apparatus. The removal of volatiles by

Table 26. Range of Percent Specific Halogenated Organic (HO) Reduction for Line Bypass Faucet-Mount, Stationary, and Pour-Through Units in the Surface Water Study

Unit	Rated capacity (gallons/liters)	Range of average percent HO reduction*		
		1	2	3
Line Bypass				
Aqualux CB-2	2000/7571	99-90	99-54	99-98
Continental Model 350	720/2725	95-95	85-95	99-99
Culligan Model SG-2	4000/15142	77-89	99-45	95-83
Everpure QC4-THM	1000/3785	99-99	99-99	99-99
Seagull IV**	1000/3785	99-99	99-99	99-98
Aquacell	2000/7571	99-96	99-80	99-89
Faucet-Mount				
Hurley Town and Country	4000/15142	99-92	99-50	99-79
Water Washer Model 1000	1000/3785	99-60	50-20	96-60
Pour-Through				
Filbrook***	300/1136	99-75	99-40	99-45
Stationary				
Sears Taste and Odor	3000/11356	79-88	51-30	78-35

1 p-Dichlorobenzene ($C_6H_4Cl_2$)
2 Hexachlorobenzene (C_6cl_6)
3 Chlordane (Technical grade, 60%)
* Range in reduction indicates gradual decline in effectiveness with time; best removals were obtained when filter was first installed.
** Units plugged prematurely
*** Filbrook was tested for 500 gallons, but results are adjusted to 300 gallons as being more representative of claimed lifetime.

Source: USEPA 1982c.

distillation, however, is a more difficult feat. If the distillation apparatus is not properly adjusted, volatile organics may vaporize with the water and condense in the distillate in a highly concentrated form. For example, it is possible that THMs present in water running through a poorly operating still can be present in the finished product at ten times their concentration in the undistilled solution (Mother Earth News 1980a). Some distillers have no distillation column and, therefore, are not capable of extracting more than one volatile at one operating temperature (Mother Earth News 1980a). Other distillers are capable of fractional distillation but require precise adjustment of the temperatures to do the job they are capable of (Mother Earth News 1980a). Still other distillers are so automated that the operator has little control over the distillation temperature (Mother Earth News 1980a). According to the chemistry reports available from the firm that manufactures this highly-automated model, this distiller has been designed to efficiently remove chloroform.

Tests to determine the efficiency of removal of carbon tetrachloride, trichloroethylene, tetrachloroethylene, 1,1,1-trichloroethane, p-dichlorobenzene, hexachlorobenzene, and chlordane by two distillers were recently conducted for the EPA, ODW, by Gulf South Research Institute during the third phase of the study (USEPA 1982c). These data were, however, discarded because an organic solvent was used, thereby invalidating the results. Consequently, no quantitative information is available on the efficiency of select distillers for removing organics from water. As a final note, distillers may also remove beneficial substances (such as essential minerals) from drinking water.

(3) Home Water Softeners. Although water can be softened in a number of ways, for the home water supply, the ion-exchange process is the most commonly used method (Clarke et al. 1977). The ion-exchange process involves the exchange of calcium and magnesium ions, which harden water, for sodium ions, which soften water (see Sections 2 and 5.1.1(2)). The exchange is accomplished by a device called a water conditioner or water softener, and the device consists of a tank filled with a natural or synthetic mineral or a synthetic resin.

There has recently been concern about the potential adverse health effects associated with soft water. Part of this concern is due to the effects the additional sodium may have on individuals on sodium-restricted diets. Another part of this concern is the indication in several studies of an inverse correlation between incidence of cardiovascular disease in humans and routine consumption of hard water. The USEPA (no date) recommends that when water must be softened, because of laundry or scaling problems, only the water being supplied to the water heater should be softened, hard water should be used for drinking and cooling. Persons concerned with sodium intake often practice split softening; others may do so as well. The advantages to consumers of softening only heated water are twofold: (1) a smaller, less-costly softener is needed, and (2) problems associated with too-soft water (e.g., soap removal) are mitigated by mixing hard (cold) and softened (hot) water to produce a moderately hard mixture.

(4) Less frequently used systems for treatment of home drinking water. Among the less frequently used systems available for treating drinking water in the home are (1) reverse osmosis units; (2) magnetic units; (3) ozonator carbon units; and (4) units that combine ultraviolet light with activated carbon.

Reverse-osmosis or membrane filters require a cartridge filter to pre-clean the water and prevent clogging. The reverse-osmosis type of filter uses a semipermeable cellulose acetate membrane which, under normal water pressure, allows the passage of water molecules but rejects impurities (Coffee 1977, Mother Earth News 1980b). According to Russo (1978), reverse-osmosis filters are capable of removing arsenic, asbestos, barium, cadmium, chromium, coliform bacteria, cyanide, iodine, iron in solution, lead, mercury, selenium, silver, other heavy metals, and radioactive elements.

Magnetic units are particularly effective in removing substances by promoting clumping of particulate matter in the liquid, thereby causing it to fall out of suspension; these units are not very effective in reducing volatile chemicals present in water (Mother Earth News 1980b).

Ultraviolet light units have no effect on suspended particles or dissolved volatile compounds. Consequently, they are also equipped with activated carbon filters which are useful for removing these substances.

The previously discussed research by Gulf South Research Institute (USEPA 1982c) that was discarded included tests of reverse osmosis and ozonator carbon units. As this was the only known study of its kind, no quantitative information is available on the efficiency of select reverse-osmosis units and ozonator units for removing organics from water. No attempts to test the efficiency of reverse-osmosis units for removing heavy metals and other substances have been conducted.

6. EXPOSED POPULATIONS

Studies of populations exposed to chemical substances via drinking water comprise three basic elements:

- Identification of exposed populations
- Enumeration of exposed populations
- Characterization of exposed populations according to age and sex.

Identification relies on information produced earlier in the methods report: examination of the sources of the chemical substance. Source examination allows the identification of the affected raw or finished drinking water supplies. The population that consumes this water is the exposed population. Once identified, the exposed population can be enumerated and characterized by the population enumeration techniques presented in Volume 4 (Section 6) (i.e., Methods for the Enumeration and Characterization of Populations Exposed to Chemical Substances) of this series. This section will summarize the population methods report and indicate how it fits into the overall assessment.

6.1 Identification of Exposed Populations

Exposed populations can be identified either through knowledge of the sources of chemical contamination or by examination of monitoring data. The former can be divided into three types of sources:

1. Sources that can be geographically defined (e.g., industrial effluents, waste disposal site leachate, and non-point sources of water pollution).
2. Sources related to the treatment processes used in production of finished drinking water (e.g., use of chemicals as coagulant aids and for disinfection).
3. Sources arising from the distribution system (e.g., dissolution of solvents from glued pipe joints).

Monitoring data, as discussed in Subsection 4.1, may identify water supplies with contamination of unknown origin.

Comprehensive identification must consider all three source types as well as available monitoring data. Volume 2 of this series (i.e., Ambient Volume) catalogs data bases and discusses and presents methods for identifying geographically defined sources of chemical contamination. Sources of contamination related to drinking water treatment processes and distribution systems are discussed in Section 5 of this volume.

Sources of contamination, having been identified, must then be keyed to water supplies, whether raw or finished, and to the consumers of those supplies. Consumers may be identified according to specific utilities when the contamination is geographically limited, or according to supply type (i.e., surface vs ground) and treatment processes when the source contamination is widespread. The following subsection briefly discusses enumeration of the exposed population.

6.2 Enumeration of Exposed Populations

There are three basic approaches for enumeration; the procedure of choice depends on how the exposed population has been identified and the financial and manpower resources available:

1. Direct contact with the utility(s) that use the contaminated water supply

2. Use of the computerized water supply inventories of either the EPA Office of Drinking Water (FRDS) or EPA Monitoring and Data Support Division (WSDB)

3. Use of generic data on population served and water supply (ground or surface), treatment, and distribution system type.

Each of these approaches is described in detail in Volume 4 (Section 6) of this series. Basically, however, direct utility contact will supply the most accurate and up-to-date information. The utilities to be contacted should be clearly defined and relatively limited so that the effort remains within the scope of available resources. It may be necessary to use one of the computerized inventories (WSDB and/or FRDS) to assemble a list of the utilities to be contacted.

The two drinking water supply inventories, discussed in detail in Section 3 of this volume, include as one of the data elements the population served by the utility. Both data bases can be used to enumerate populations that consume surface supplied water; however, only FRDS has data on populations who derive drinking water from ground water supplies.

The population data in FRDS is much more accurate than the same data in WSDB. FRDS is updated yearly and thus reflects the population data collected by individual states the previous year. FRDS population data can be retrieved according to the following:

- EPA Region
- State
- County
- City or utility.

An FRDS retrieval may be further restricted according to ground water or surface water and according to treatment process(es). Retrievals for specific geographic categories should exclude utilities that purchase their water supply from other utilities. These utilities are designated with a P code in the FRDS inventory.

The utilities that sell drinking water, either raw or finished, to other utilities include the population of the purchasing utility in their total population figures. This retrieval restriction, therefore, will prevent counting populations twice.

Finally, populations that obtain their drinking water from household wells may be approximated by retrieving all populations served by public or private community water systems for the geographic category of interest, as listed above, and subtracting this total from the total population of the geographic category as recorded in the 1980 Census of Population. Retrievals from the FRDS inventory should be directed to:

Mr. Avrum Marks
Manager-Computer Systems Staff
EPA-Office of Drinking Water
401 M Street, S.W.
Washington, DC 20460
(202) 382-5513

The population data included in the WSDB inventory contain two levels of accuracy. The data for surface water utilities that serve populations greater than 25,000 are very accurate, reflecting information obtained via direct phone contact with these utilities in 1981 (Versar 1981). The data for surface water facilities serving fewer than 25,000 were collected from a nationwide inventory conducted in the late 1960s and early 1970s (Versar 1981).

The major advantage in using the WSDB inventory for retrieving population data is the integrated assessment approach to identifying industrial and POTW sources of contamination, affected surface water supplies, USGS gages which contain flow data, and the municipal or private systems that use the affected surface water as raw water supply. This approach, the retrieval categories and applicable programs, and the EPA office to which retrievals should be directed are discussed in detail in Subsection 3.1. To obtain the most accurate accounting of exposed populations, a comprehensive exposure assessment should access the population data contained in both EPA drinking water supply inventories.

Exposed populations may also have to be enumerated by the use of generic data on population served and water supply, treatment, and distribution system type. This approach is applicable when the sources of contamination are widespread and no specific water supplies are identified. The population methods report (Volume 4, Section 6) has generic data on population served by water supply type, treatment process, and distribution system materials.

Finally, a rather crude system of enumerating exposed populations based on the use of sample monitoring data can be used. The method extrapolates data on the frequency of detection of the substance. It is described in detail in Volume 4. The method, however, should only be used in the absence of more refined data.

6.3 Characterization of Exposed Populations

Drinking water intake rates are a function of the individual's age and sex as described in the following section. In order to obtain a precise exposure distribution, therefore, the exposed population must be characterized according to age and sex. If the chemical substance of interest has special effects on particular age classes such as the elderly or children, further characterization of the enumerated population is indicated. It is also possible, for example, that a chemical substance is determined to be teratogenic; enumeration of women of childbearing age may be then required.

The simplest and most rapid method of characterizing a large population is to assume that the age and sex distributions approach those of the total U.S. population. Volume 4, Section 2, of this series has data depicting the age and sex distribution by percent for the total U.S. population. Characterization within specific geographic areas, such as states, counties, cities and townships, involves the use of Bureau of Census publications also described in Volume 4, Section 2.

7. CALCULATION OF EXPOSURE

Human exposure via contact with drinking water may occur through three exposure routes: ingestion, dermal contact, and inhalation. Of these, the first is usually considered the most significant, through the latter two (dermal contact and inhalation) may be important if the chemical being assessed has certain physical/chemical properties. Calculating exposure for each of the three possible routes is discussed below.

7.1 Ingestion Exposure

To calculate the annual rate of exposure to an individual as a result of ingesting chemical substances in drinking water, three items of information are necessary: (1) the concentration of the chemical substance in drinking water expressed in mg/l or ug/l, (2) the daily rate of intake of drinking water in l/day or l/kg/day, and (3) the number of days per year the individual consumes water from the source containing the chemical substance. The annual exposure rate, as calculated below, is expressed in mg/year, ug/year, mg/kg/year, or ug/kg/year:

$$E = I \times C$$

where

E = exposure in mass/time or mass/unit body weight/time

I = intake rate, in volume/time or volume/unit body weight/time

C = concentration of chemical substance in mass/volume.

The accepted standard drinking water intake rate is 2 liters per day (NAS 1977, USEPA 1980). It must be noted that the intake rate for drinking water and the corresponding volume consumed vary with age and sex; these intake rates and corresponding volumes consumed are presented in Table 28.

The example that follows illustrates how the annual rate of exposure to an individual as a result of ingesting chemical substances in drinking water is obtained.

> A drinking water supply contains chloroform at a concentration of 50 ug/l. A 1-year old male of median weight for his age group drinks all of his water from this supply 365 days per year. What is the extent of this individual's annual chloroform exposure?

> To calculate exposure, consult the data provided in Table 27. According to this table, a 1-year old male consumes .25 l/kg/day of drinking water. For a 1-year old male of median weight, this corresponds to 2.53 l/day. The annual drinking water intake rate is obtained by multiplying the concentration of chloroform by the drinking water intake rate by the number of days the drinking water is consumed per year as follows;
>
> (50 ug/l)(.25 l/kg/day)(365 days/year) = 4,563 ug/kg/year
>
> A 1-year old male of median weight weighs 10.1 kg. Multiplying 10.1 kg by 4,563 ug/kg/year yields a resultant exposure to this individual of 56,086 ug/year or 56 mg/year.

In deriving exposure values, one may wish to take into account the possibility that an individual may use drinking water from more than one source. For example, at home the individual may use a private source of drinking water, but at work a public source may be used. Another possibility is that at home an individual may use a public source of drinking water, but at work another public source may be used. Taking these factors into consideration would require that separate assessments be performed for each source of drinking water for an individual.

7.2 Dermal Exposure

Dermal absorption of pollutants may occur as a result of contact with potable water during showering, bathing, housecleaning, dishwashing, etc. The relative significance of this exposure route varies by chemical. It is often disregarded, but Brown et al. (1984) recently estimated that dermal exposure can comprise from 29 to 91 percent of the daily dose of lipophilic (i.e., high log K_{ow}) (octanol-water partition coefficient) compounds, with an average of 64 percent.

The method used by Brown et al. (1984) was similar to that discussed in detail by Scow et al. (1979). Data requirements include concentration of contaminant in water, a permeability constant (chemical-specific), duration of exposure, and body surface area exposed. Fick's law is the basis of the method. Scow et al. (1979) presents permeability constants and some data on duration and frequency of water-contact activities. Volume 7 of this series presents detailed information on body surface areas.

7.3 Inhalation Exposure

Inhalation exposure can occur when a chemical volatilizes from drinking water or when the water becomes a mist or aerosol with droplets of

Table 27. Drinking Water Intake Rates and Volumes Consumed by Age and Sex

Age	l/kg/day[a]		50th Percentile weight in kilograms[b]		l/day	
	Male	Female	Male	Female	Male	Female
Birth	.26	.21	3.40	3.25	0.88	0.68
6 mos.	.26	.21	7.82	7.20	2.03	1.51
1	.25	.20	10.10	9.57	2.53	1.91
2	.22	.18	12.57	11.97	2.77	2.15
3	.20	.16	14.61	13.95	2.92	2.23
4	.18	.14	16.55	15.99	2.98	2.24
5	.16	.13	18.70	17.90	2.99	2.33
6	.13	.11	20.84	20.12	2.71	2.21
7	.11	.09	23.54	22.49	2.59	2.02
8	.08	.07	26.30	25.16	2.10	1.76
9	.06	.05	29.31	27.95	1.76	1.40
10	.04	.04	32.96	31.42	1.32	1.26
11	.04	.04	36.90	35.71	1.48	1.43
12	.04	.04	40.37	41.91	1.61	1.68
13	.04	.04	46.74	46.45	1.87	1.86
14	.04	.03	52.93	50.74	2.12	1.52
15	.04	.04	59.87	52.85	2.39	2.11
16	.04	.04	64.93	53.85	2.60	2.15
17	.04	.04	68.30	55.05	2.73	2.20
18-74	.03	.02	69.0	63.7	2.07	1.27
18-24	.03	.02	69.7	64.3	2.09	1.29
25-34	.03	.02	69.5	64.0	2.09	1.28
35-44	.03	.02	69.2	64.1	2.08	1.28
45-54	.03	.02	68.8	63.7	2.06	1.27
55-64	.03	.02	68.2	62.8	2.05	1.26
65-74	.03	.02	67.3	62.3	2.02	1.25

[a] USEPA 1982d.

[b] USDHEW 1977; 1979.

respirable size. The volatility of a compound determines, in large part, the significance of this exposure route. No sophisticated exposure assessment methods have been created, though screening-level calculation may proceed as described below.

This exposure route is most likely to become important when the water is heated and dispersed as a mist; such may be the case during a shower. An example screening calculation for daily exposure to a volatile compound (e.g., a chemical substance with a vapor pressure $>10^{-3}$ mm of Hg @ 20°C (Lyman et al. 1982)) is as follows:

Amount of water used = 5 gal/min (Richards 1981)
x 10 minutes/shower (assumed)
= 50 gallons (190 liters)

Concentration = 50 ug/l (assumed)

Loading = 50 ug/l x 190 l = 9500 ug
(assuming all volatilizes)

Air concentration (simple dilution) $= \dfrac{9500 \text{ ug}}{2 \times 3 \times 2 \text{ m bathroom}} = \dfrac{9500 \text{ ug}}{12 \text{ m}^3}$

$= 790 \text{ ug/m}^3$

Exposure = 790 ug/m^3 x 1 m/hr (inhalation rate)
x 0.33 hr (assumed duration in bathroom)

= 260 ug/day (assuming one shower per day)

The above approach provides a rough approximation of exposure. A detailed analysis requires use of the chemical's physical-chemical properties and liquid-air mass transfer coefficients to predict inhalation concentrations. This type of analysis is outside the scope of this report; information and estimation techniques, however, may be obtained from Lyman et al. (1982).

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